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# Study of historical nuclear reactor discharge data

**Better Regulation Science Programme**
Science report: SC070015/SR1

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Steve Killeen

Steve Killeen

**Head of Science**

# Executive summary

Before any new nuclear reactor can be authorised for construction and operation in the UK, its design must be thoroughly assessed and then approved for license. The Environment Agency's role in this process is to regulate the operations of any new nuclear power station against the requirements of relevant legislation, such as the Radioactive Substances Act (1993) and the Environmental Protection Act (1990).

In response to a request from the UK Government (following the Energy Review in 2006), designs for new reactor stations in the UK are assessed by the regulators following a process called the Generic Design Assessment (GDA). The GDA will essentially determine whether reactor designs satisfy the safety, security and environmental requirements for licensing and authorisation of nuclear power stations in the UK. As part of the GDA, the Environment Agency will assess the discharges to the environment from a new nuclear power station.

On behalf of the Environment Agency, AREVA Risk Management Consulting Ltd has conducted this study of actual discharges at operating nuclear power stations with reactor designs that are effectively precursors to the four generic designs submitted by vendors for GDA.

The generic designs are:

- the AP1000, submitted by Westinghouse;
- the European Pressurised Reactor (EPR), submitted by Electricité de France (EDF)/Areva;
- the Economic Simplified Boiling Water Reactor (ESBWR), submitted by GE-Hitachi;
- the ACR-1000, submitted by Atomic Energy of Canada Ltd (AECL).

AREVA Risk Management Consulting Ltd analysed available data on levels of radioactive liquid and airborne discharges from a list of predecessor nuclear reactor power stations agreed with the Environment Agency. The predecessors included stations with examples of reactors that are immediate predecessors of the new designs, or that are earlier-generation designs with at least 10 years of available operational data.

The activities, successes and failures, that AREVA Risk Management Consulting Ltd experienced in attempting to collate relevant data are presented in this report. The operators of the selected sample stations were contacted, but with limited success. The primary sources of data for this study were publicly available regulatory reports into discharges, especially reports from the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the EU and data published by nuclear regulators in the USA, Japan and the International Atomic Energy Authority (IAEA). Information gaps have been identified and are outlined in detail.

The later sections of the report include descriptions of the analysis that has been undertaken on the data, which includes:

- analysis of like radionuclides discharged from each candidate reactor included in this study, to identify trends. Where possible, an explanation for any trends identified has been provided;
- analysis of like radionuclides discharged from each class of candidate reactor included in this study, to identify the expected discharges under

normal operational conditions. Where possible, explanations are provided for any significant deviations from the average discharge range calculated.

The analysis included both raw (non-normalised) annual discharge data and values that had been normalised by the electrical and thermal output of the candidate station (i.e. discharge per unit of generated electrical or thermal energy). In some cases (but not all) the normalisation step eliminated apparent peaks in discharges, showing that discharges are proportional to the output of a reactor. Where evidence was available, peaks in discharges have been classified as abnormal or operational releases.

A number of conclusions have been made concerning the analysis of the data, and the findings of this study are presented in Chapter 6. Different reactors performed best for different discharge groups; no single reactor could be classified as having better overall performance.

However, from the collated data it can be concluded that the ACR-1000 predecessors give the highest total liquid and airborne discharge averages and highest standard deviations. The ESBWR predecessors give the lowest total liquid and airborne averages and the lowest standard deviations. The EPR and AP1000 predecessors both show small variation in total liquid and airborne averages, when compared with the ACR-1000 and ESBWR predecessors.

The historical discharges were compared with the predicted discharges for the four generic designs. In some cases the predicted discharges were higher than the average historical discharges from predecessors, in some cases lower or in line. However, it is recognised that the requirements for reporting and predicting discharges depend on the policies of the reactor power station, the design vendors and the regulatory regime within the operating nation. Such variations need to be taken into account for a fair comparison between discharges to be made. Furthermore, the predicted discharge value used in this report was taken from the vendors' GDA submissions of August 2007. These values may since have been amended during the GDA process.

The conclusions drawn are by no means complete, and should be looked upon in conjunction with the methodology described in Chapter 2. A particular limitation of the work is related to the method of reporting which radionuclides were discharged. For example, noble gases may be reported as a group or by individual radionuclide. Another issue is that data is reported for a nuclear power station rather than a specific reactor, making it difficult to determine the cause of any observed abnormalities in discharge.

Future work should focus on updating or filling data gaps in the historical record of discharges from the nuclear reactors. It is suggested that a review of the data contained in the forthcoming UNSCEAR publication (which was expected to be published in 2007) would be beneficial. Investigating the radiological impact of the discharges in the context of local, climatic and other effects might also help to explain some of the variation observed in the discharge data.

# Acknowledgements

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# Contents

## List of Tables

# List of Figures

# 1. Introduction

## 1.1 Background

Before any new nuclear reactor can be authorised for construction and operation in the UK, its design must be thoroughly assessed and then approved for license. The primary regulatory bodies involved in this process are the Environment Agency and the Nuclear Safety Division of the Health and Safety Executive (the NSD). The Environment Agency's regulatory role in the nuclear power industry is to regulate the operations of any new nuclear power station against the requirements of relevant legislation, such as the Radioactive Substances Act (1993) and the Environmental Protection Act (1990).

In response to a request from the UK Government (following the Energy Review in 2006), the two regulators have developed the Generic Design Assessment (GDA) process for proposed reactor designs for new nuclear power stations (HSE, 2007). The GDA will essentially determine whether reactor designs satisfy the safety, security and environmental requirements for licensing and authorisation of nuclear power stations in the UK. The regulators plan to make statements at key stages during the GDA process.

To date, four generic reactor designs have been submitted for assessment against the requirements for licensing and authorisation to operate in the UK. These generic designs are:

- the AP1000, submitted by Westinghouse;
- the European Pressurised Reactor (EPR), submitted by Electricité de France (EDF)/Areva;
- the Economic Simplified Boiling Water Reactor (ESBWR), submitted by GE-Hitachi;
- the ACR-1000, submitted by Atomic Energy of Canada Ltd (AECL).

A significant issue of interest to the Environment Agency is the potential for discharges to the environment. On behalf of the Environment Agency, AREVA Risk Management Consulting Ltd has conducted this study of actual discharges at operating nuclear power stations with reactor designs that are effectively precursors to the generic designs submitted for GDA.

The output from this study will be used by the Environment Agency to inform its assessment of Best Available Techniques (BAT).

## 1.2 Objectives

The objectives of the study were:

- to assemble historical discharge data for operational reactors from which the four generic reactor designs have evolved;
- to provide information on how the data were derived (e.g. measurement or calculation) and to normalise the information to electrical output and thermal output;

- to gather information on solid wastes produced from the treatment and abatement of liquid and airborne wastes prior to discharge during the historical period covered by the data;
- to gather design and operating information on a target group of reactor power stations, including data on the types of abatement plant used, and operating problems during the period;
- to analyse the collated data and draw technical links between discharge performance and plant specification, operation and maintenance;
- to interpret differences between reported discharge parameters and rationalise these to allow sensible comparisons to be made;
- to explain the differences between individual reactor performance in terms of design, operation and maintenance;
- to establish whether better performance on gaseous or liquid discharges is achieved at the expense of increased quantities – volume or activity – of solid wastes, worker dose or non-radioactive impact on the environment.

## 1.3 Scope

This report presents the findings of the study, including:

- the identification and formal agreement with the Environment Agency of a list of candidate reactors that best represent the predecessors to the four designs submitted for GDA;
- the identification and formal agreement with the Environment Agency of a format of information to be used for this study;
- the collection and collation of relevant information required for this study;
- the presentation and analysis of collated data relevant to each candidate reactor and discharge medium (liquid and airborne) in:
    - its raw state, and;
    - normalised by the electrical and thermal output of the reactor;
- the presentation of an inferred range of discharges calculated from the mean and mean plus standard deviation of discharges by radionuclide group and reactor type;
- comparison of collated data against the discharges predicted by the vendors in their GDA submissions of August 2007.

# 2. Methodology

## 2.1 Stage 1 – data sources

### 2.1.1 Identifying the list of candidate reactors

At least six existing operational reactor power stations for each of the proposed new designs were proposed for this study. A number of factors (listed below) were considered to set the criteria used to propose which operational reactor power stations to include in the study.

i. The design of the reactor(s) at each candidate reactor power station.

   Where possible, those reactor power stations chosen had reactors with designs that are immediate predecessors to the new designs included in the GDA process.

   Where immediate predecessors were not available, reactor power stations were selected if they had examples of the predecessor to the predecessor (i.e. the second predecessor to the new designs included in the GDA process).

ii. The operational period of the reactor(s) at each candidate reactor power station;

   Where possible, selected reactor power stations not only had reactors with designs relevant to the first criteria (above), but also had been operational for an optimal period of 10 years.

   This optimal operational period of 10 years was chosen because:

   - it would provide sufficient data to identify characteristics and trends in discharges relevant to operational practices;
   - it would allow for ease of comparison with the only existing pressurised water reactor (PWR) in the UK, Sizewell B which offered at least 10 years worth of operational experience.

   It was not always possible to identify reactors that fulfilled both of these criteria (i.e. reactors that were examples of the immediate predecessor to the GDA designs and had been operational for 10 years). Consequently, a set of candidate reactors was proposed that represented:

   - the immediate predecessor designs;
   - examples of the second predecessor designs, that have been operational for the optimal period of 10 years.

iii. The accessibility of data required for the study.

   The third criteria used to select suitable example reactor power stations for this study was the availability and accessibility of relevant data. Reactor power stations were excluded from the candidate list if it was thought that it would take a considerable amount of time to confirm that suitable sources of information for this study were available.

### 2.1.2 Identifying sources of data

This study involved collecting available and accessible discharge and waste data spanning the lifetime of the reactor plant during operational, plant shutdown and maintenance periods. The data included:

- radioactive liquid and gaseous discharge data (activity and volume);
- key radionuclides in discharges;
- abatement technologies used;
- radioactive solid wastes generated, in treating liquid and gaseous releases (activity and volume);
- electrical and thermal power output;
- operator dose from radioactive waste operations.

AREVA Risk Management Consulting Ltd was able to secure viable sources of data for this study by:

- contacting the operators of nuclear reactor power stations, as summarised in Section 3.2.1;
- viewing the websites and contacting the vendors of the four designs, as summarised in Section 3.2.2;
- viewing the websites and attempting contact with relevant national nuclear regulators, as summarised in Section 3.2.3;
- viewing the websites of some international sources of information (i.e. UNSCEAR and IAEA);
- accessing data from some national sources of information (e.g Radioactivity in Food and the Environment – RIFE).

### 2.1.3 Liquid and gaseous discharge fingerprinting to define the reporting groups

When sources of data relevant to liquid and gaseous discharges were confirmed, AREVA Risk Management Consulting Ltd identified differences in the format of data available for the candidate reactor power stations included in this study. Consequently, the reported raw data was not sufficiently compatible to permit practicable comparisons between the candidate reactor power stations.

For example, the regulatory body in the United States of America (USA), the Nuclear Regulatory Commission (NRC), reported liquid and gaseous radioactive discharge data in terms of individual radionuclides. The Japan Nuclear Energy Safety Organisation (JNES), however, reported liquid and gaseous discharge data by grouping radionuclides.

To circumvent these incompatibilities, a fingerprint of radionuclide groups was developed to facilitate comparison between the environmental discharges from each candidate reactor power station. The fingerprint was influenced by the availability of relevant radionuclide data and was based on a number of assumptions (detailed in Section 3.3).

### 2.1.4 Information gaps

In order to identify gaps in available information for each of the candidate reactors, a spreadsheet was set up with columns for each nuclide or nuclide group reported for each reactor. The years for which each nuclide or nuclide group discharge data was reported by each information source was then recorded in the spreadsheet.

The spreadsheet was then analysed and any gaps in information for each candidate reactor were noted. The information gaps identified are shown in Section 3.4.

## 2.2 Stage 2 – collecting and collating data

### 2.2.1 Validation and quality assurance of data

For cases where two or more data sources were available for a candidate reactor, the sources were cross-checked against the data used for this study. In addition, peaks and troughs in the data were checked against the data source as a check for potential errors in data entry.

### 2.2.2 Trends identified in discharge data

For each candidate reactor, the relevant data (from the sources identified in Section 3.2.4) were entered into a spreadsheet in a standard format. This standard format provided the framework for recording information for each of the nuclide groups (see methodology described in Section 3.3.

Charts were then generated for each nuclide group and for each candidate reactor. These charts were then used to identify trends in discharges for each candidate reactor.

The charts produced and details of the trends identified are described in Chapter 4.

### 2.2.3 Average discharge data relevant to reporting group and reactor class

It was also necessary to compare discharges from the candidate predecessor reactors for each of the four proposed designs, therefore multi-reactor charts were produced for each nuclide group.

The average discharge for each design was calculated and illustrated on the graph. Additionally, the sum of the average and the standard deviation was used to provide the statistical range of discharges evident from the data available.

The calculation of average (or mean) is to some extent an iterative process. It was assumed that the range represented by the mean and the mean plus the standard deviation (maximum) is representative of the range of discharges expected during normal operation.

Some peaks in the data were judged (by experts) to be significantly greater than the normal range and these were investigated further. Relevant sources were queried for evidence of abnormal events that might provide an explanation for the significant peaks. Cases for which evidence was found have been marked on the graphs and the data removed from the mean and mean plus standard deviation calculations.

Consequently, the graphs not only allow comparisons to be made for a particular nuclide group across the four proposed designs, but they also help to identify any potentially abnormal peaks in discharges.

## 2.3 Stage 3 – electrical normalisation

### 2.3.1 Discharge rate per GWeh

For each of the candidate reactors identified, the following information from the IAEA Power Reactor Information System (PRIS) database (IAEA, 2008a) was collated into a Microsoft Excel spreadsheet:

- annual electrical power output (in GWeh);
- annual online time (in hours).

For power stations where multiple reactor cores were in operation (e.g. Beaver Valley, Darlington, etc.), the annual electrical output and online time was obtained by summing the figures for all reactor units present.

The collated liquid and airborne discharge data was then normalised by dividing the raw data by the annual electrical output (net electrical energy generated) to provide the discharge per GWeh for each of the candidate power stations included in this study.

### 2.3.2 Predicted discharge data for proposed new designs

A similar method was used to normalise the predicted discharges for the proposed new designs by electrical output.

The annual electrical power output was derived from the electrical capacity for each proposed reactor as stated in the GDA submissions (HSE, 2007). It is recognised that reactors would not be available 100 per cent of the time, due to maintenance and refuel activities. However for the purpose of this study, it was assumed that the discharges predicted for each reactor in the GDA design were based on the reactor operating at 100 per cent capacity i.e. for 24 hours a day, 365 days a year. Therefore the annual electrical power output for each proposed reactor design is given by:

$$\text{Annual Electrical Output} = \text{Design Capacity (GWe)} \times 365 \times 24 \times \text{Number of reactor cores}$$

The predicted discharges for each proposed design were then divided by this theoretical annual electrical power output to obtain a normalised discharge for the proposed new designs in GBq/GWeh.

## 2.4 Stage 4 – thermal normalisation

### 2.4.1 Historical operational data

As no information source was available for historical annual thermal output data, the thermal output data were derived from the electrical output data gathered in Section 2.3 and the net electrical capacity for each candidate reactor (IAEA, 2008a) using the following equation:

$$\text{Thermal Output} = \frac{\text{Thermal Capacity of Candidate Reactor}}{\text{Net Electrical Capacity of Candidate Reactor}} \times \text{Electrical Output}$$

The thermal and net electrical capacities were obtained from the World Nuclear Association (WNA) reactors database (WNA, 2008). For reactor sites where multiple reactor cores are present (e.g. Beaver Valley, Darlington, etc.), the thermal and net electrical capacities were derived by the sum of the respective capacities for all cores present.

The raw discharge data was then divided by the derived thermal output to give the discharge per GWth of energy generated.

### 2.4.2 Predicted discharge data for new proposed designs

The same method used in Section 2.3.2 was used to normalise the predicted discharges by thermal output for the new proposed designs. It is recognised that reactors would not be available 100 per cent of the time. However, for the purpose of this study, it was again assumed that the predicted discharges quoted for each reactor in the GDA submissions were based on the reactor operating at 100 per cent capacity (i.e. for 24 hours a day, 365 days a year), with the annual thermal power output for each proposed reactor design given by:

$$\text{Annual Thermal Output} = \text{Design Capacity (GWt)} \times 365 \times 24 \times \text{Number of reactor cores}$$

The predicted discharges for each proposed design were then divided by this theoretical annual thermal power output to obtain a normalised discharge for the new proposed designs in GBq/GWth.

## 2.5 Indicative operational range analysis

A method was developed to estimate the range of discharges expected under normal operations. The method takes account of the following key factors:

i. Each class of reactor is represented by a dataset compiled from a small number of individual reactor power stations.

   However, the data has been used to estimate the performance of the reactor class as a whole.

ii. The assumption that the data points produced by the population of reactor power stations follow a normal Gaussian distribution is tenuous.

   Reactor discharges are dependent on many operational factors (e.g. plant shutdown and re-fuel operations, maintenance operations, the efficacy of the installed abatement plant, plus abnormal events or accidents). It is difficult to justify that resultant discharges from a large population of power stations will follow a normal Gaussian distribution. However, for reasons of practicality this is an assumption that has been made.

iii. The range of discharges can be estimated based on a measure of the variance in the data collated.

### 2.5.1 Estimation of the average (mean) from the collated sample

The mean, calculated from the data collated for this study, is only truly representative of the small dataset itself. However, by applying confidence interval theory, a range about this mean may be calculated; the mean for the larger un-studied population can be expected to fall within this range. Applying 99 per cent confidence limits will produce values within which the average (mean) for the larger population of reactor power stations can be expected to fall:

$$\mathrm{CL}_{99\%} = \mathrm{mean} \pm 2.57853\sigma$$

For the purposes of this study, however, the mean calculated from the study sample is assumed also to be representative of the mean for the larger un-studied population of reactor power stations.

### 2.5.2 Statistical standard deviation

In statistics, the standard deviation is defined as the square root of the variance and is a measure of the variability of data points in a given dataset or study sample. In this study the standard deviation was used in addition to the average (mean) to estimate the range in discharges that might be expected under normal operations. This range is based solely on the variability of data points evident in the study data collated.

### 2.5.3 Indicative operational range

Significantly and abnormally high annual discharge data points (as identified by expert judgement) of a single class were removed from the mean and standard deviation calculations (see Section 2.2.3). These “extreme” data points were disregarded because it was conceived that significant peaks may contain contributions from abnormal events; by removing these peak values, the estimated range of discharges would be representative of discharges under normal operations alone. A value for the average (mean) discharge corresponding to each reactor type was calculated for each discharge group.

A theoretical maximum for the discharges was also calculated, given by:

Maximum Discharge = Average (mean) Discharge + Standard Deviation

This estimate is therefore based on some significant assumptions, not least that the mean calculated from the study sample can be considered representative of the mean for the population as a whole (see Section 2.5.1).

This method has been adopted because it provides a convenient range with which to compare discharges. Nevertheless, given the significant assumptions and consequent limitations of the method, there should not be too much emphasis placed on justifying the statistical method used to arrive at the values derived.

Despite the additional work to identify abnormal events that might partly support the exclusion of the significantly higher discharge values, evidence of abnormal events was not always found for all the data points excluded from the average and standard deviation calculations. The principle information sources for this additional research included:

- the USA NRC website for the AP1000 and ESBWR predecessors;
- JNES website for ESBWR predecessor reactors;

- the Canadian Nuclear Safety Commission (CNSC) website for ACR-1000 predecessor reactors.

For the EPR, and in cases where the above information sources did not provide any evidence for the cause of the peaks, a broad web search was also carried out.

# 3. Data sources

## 3.1 Identifying the list of candidate reactors

A certain amount of iteration was necessary before the list of candidate reactors for the study was agreed with the Environment Agency. The formal and finally agreed list includes examples of reactor power stations that are a mix of:

- those that had been operating for a nominal 10 years or more;
- those that contained examples of reactors that are judged to be the immediate predecessors to the generic designs proposed for GDA.

For example, the two EDF (N4) reactor power stations at Chooz and Civaux house reactors that are immediate predecessors to the EDF/Areva EPR, but they have been operational for no more than eight years. As a result, the two reactor power stations at Golfech and Penly were added to the list; these stations have been operating the predecessor to the EDF (N4) design since the early 1990s.

Similarly, the power station at Isar (Germany) contains an example of the most recent Konvoi reactor, judged to be another immediate predecessor to the EDF/Areva EPR design. However, the Konvoi unit at the Isar power station has only been operational for four years. As a result, the two power stations at Neckarwestheim and Emsland were included in the list as they contain examples of earlier Konvoi reactors that have been operational for the nominal 10 years of study.

The power stations chosen to represent the predecessors to the Westinghouse AP1000 design include Sizewell-B, the only example in the UK of a PWR designed by Westinghouse. Additional power stations of this type were chosen on the basis that their present reactor units have all been operational for the nominal 10 years of study. Four operational power stations were selected from the USA (Beaver Valley, Byron, Comanche Peak and Seabrook) and one was chosen from Japan (Takahama).

The power stations chosen to represent the predecessors to the GE-Hitachi ESBWR design include those that operate the only existing examples of operational Advanced Boiling Water Reactors (ABWRs). These include:

- Hamoaka, which operates one ABWR and four BWRs;
- Kashiwazaki-Kariwa, which operates two ABWRs and five BWRs;
- Shika, which operates one ABWR and one BWR.

Additional power stations of this type were chosen on the basis that they have BWR units and have also been operational for the nominal 10 years of study. The additional power stations include Clinton and Nile Mile Point in the USA and Shimane in Japan.

Following a request by the Environment Agency, a number of reactor power stations were included in the study, but sources for the required data were not available. The power stations include the CANDU reactor power stations at Cernavoda in Romania and Wolsong in South Korea. These are predecessor designs to the ACR-1000.

The agreed list of candidate reactors for inclusion in this study is provided in Table 3.1.

**Table 3.1 List of candidate reactors.**

| Reactor Class | Country | Type | Power Station | Start-up |
|---|---|---|---|---|
| **EDF/Areva EPR** | France | EDF (N4) | Chooz | 2000 |
| | France | EDF (N4) | Civaux | 2002 |
| | France | EDF | Golfech | 1991–1994 |
| | France | EDF | Penly | 1990–1992 |
| | Germany | Konvoi | Neckarwestheim-2 | 1989 |
| | Germany | Konvoi | Emsland | 1988 |
| | Germany | Konvoi | Isar-2 | 1988 |
| **Westinghouse AP1000** | USA | Westinghouse | Beaver Valley-2 | 1987 |
| | USA | Westinghouse | Byron-2 | 1987 |
| | USA | Westinghouse | Comanche Peak-1 | 1990 |
| | USA | Westinghouse | Seabrook-1 | 1990 |
| | UK | Westinghouse | Sizewell B | 1995 |
| | Japan | Westinghouse | Takahama | 1974–1984 |
| **GE-Hitachi ESBWR** | Japan | BWR, ABWR | Kashiwazaki | 1985–1997 |
| | Japan | BWR, ABWR | Hamaoka | 1974–2004 |
| | Japan | BWR, ABWR | Shika | 1993–2005 |
| | Japan | BWR | Shimane | 1974–1989 |
| | USA | BWR | Clinton-1 | 1987 |
| | USA | BWR | Nine Mile Point-2 | 1988 |
| **AECL ACR-1000** | Canada | Candu | Bruce | 1977–1987 |
| | Canada | Candu | Darlington | 1992–1993 |
| | Canada | Candu | Gentilly-2 | 1983 |
| | Canada | Candu | Pickering | 1971–1986 |
| | Canada | Candu | Point Lepreau | 1983 |
| | Romania | Candu | Cernavoda | 1996 |
| | South Korea | Candu | Wolsong | 1983–1999 |

Notes: Although Beaver Valley-2, Byron-2 and Comanche Peak-1 are shown in the above table as candidate reactors, the data collated correspond to both cores at each of the sites; i.e. Beaver Valley-1 and -2, Byron-1 and -2 and Comanche Peak-1 and -2. This is due to the format in which discharge data were available.

## 3.2 Identifying viable sources of data

### 3.2.1 Operators of nuclear power stations

Operators of the selected predecessor nuclear reactors were contacted and asked for information on discharges from their stations. Two emails were sent to each operator. On 22 November 2007 an email (in some cases an on-line form) was sent to the operators to request discharge and other information from the reactors, as detailed in Section 2.1.2. A follow-up email (in some cases on-line form) was sent on 30 November 2007. The list of contacted operators is provided in Table 3.2.

**Table 3.2 List of contacted operators.**

| Successor Design | Operator | Outcome |
|---|---|---|
| **AECL ACR-1000** | Ontario Power Generation | No response |
| | Hydro-Quebec | No response |
| | New Brunswick Power | No response |
| | Tokyo Electric Power Co (Kashiwazaki-6 and -7 operator) | No response |
| | Chubu Electric Power Co (Hamaoka-5 operator) | Provided information gathered by the JNES |
| | Hokuriku Electric Power Company (Shika-1 operator) | No response |
| | Chugoku Electric Power Co (Shimane-3 operator) | No response |
| **EDF/Areva EPR** | Electricité de France | No response |
| | RWE Power (Emsland owner) | Provided UK RWE contact: UK Nuclear Development Group, RWE, UK |
| | E.ON Kernkraft (Isar-2 owner) | No response |
| | EnBW Kraftwerk AG (Neckarwestheim owner) | No response |
| **Westinghouse AP1000** | First Energy | Responded – Referred to state (Ohio and Pennysylvania) and NRC |
| | Exelon Nuclear Co | No response |
| | Ameren | No response |
| | Duke Power Co | Declined to help |
| | TXU Electric Co | No response |
| | Pacific Gas | No response |
| | Indiana Michigan Power Co | Declined to help |
| | Southern Nuclear Operating Co | No response |
| | Progress Energy Corp | Responded but no useful information provided. |
| | Entergy Nuclear | No response |
| | Dominion Virginia Power | No response |
| | Nuclear Management Co | No response |
| | Nuclear Management Co, FPL | Declined to help |
| | Public service electric | No response |
| | Florida Power | Declined to help |
| | South Carolina Electric | Responded but no useful information provided. |
| | Constellation Energy | No response |
| | Tennessee Valley Authority | Responded – Referred to NRC |
| | Wolf Creek Nuclear | No response |
| | STP Nuclear Operating | No response |
| | Centrales Nucleares Almaraz-Trillo (Almaraz-1 and -2 operator/owner) | No response |

Table 3.2 continued overleaf

**Table 3.2: continued**

| Successor Design | Operator | Outcome |
|---|---|---|
| **Westinghouse AP1000** | Asociacion Nuclear Asco-Vandellos A.I.E<br>(Asco-1 and -2 and Vandellos-2 operator/owner) | No response |
| | Union Fenosa Generation S.A<br>(Jose Cabrera-1 operator/owner) | No response |
| | British Energy | Response received – directed us to Environment Agency for information |
| | Kansai Electric Power Co.<br>(Mihama-1, Ohi-1 and -2, Takahama-1 operator) | No response |
| **AECL ACR-1000, Westinghouse-AP1000, EDF/AREVA EPR** | Korea Hydro & Nuclear Power Co. Ltd<br>(Wolsong, Yongwang, Kori and Ulchin operator) | No response |

### 3.2.2 Vendors of the generic reactor designs

The vendors of the generic reactor designs – AECL, Westinghouse, EDF/Areva and GE-Hitachi – were contacted during late November 2007. Only AECL has provided assistance with this study.

### 3.2.3 Regulatory bodies

Some regulatory bodies were contacted in December 2007. These included:

- USA Nuclear Regulatory Commission (NRC);
- Canadian Nuclear Safety Commission (CNSC);
- Japan Nuclear Energy Safety Organisation (JNES).

To date, only the CNSC and the JNES have provided assistance with this study.

In addition, the Nuclear Waste Management Organisation (NWMO) in Canada was also contacted. However, no response was received.

### 3.2.4 Viable data sources identified

Sources of liquid and gaseous radioactive discharge data have been found for most candidate reactors included in this study. The sources of data have included publicly available online databases and reports. A summary of the data sources can be found in the following matrix (Table 3.3).

**Table 3.3 Matrix summarising the data sources used in this study.**

| Country | Reactor Types | Gaseous Discharge | | Liquid Discharge | | Solid Waste | Output Power | Occupational Dose | Power Factors |
|---|---|---|---|---|---|---|---|---|---|
| **UK** | Westinghouse – PWR | UNSCEAR (1990–1997) | RIFE (1995–2006) | UNSCEAR (1990–1997) | RIFE (1995–2006) | | IAEA PRIS | | IAEA PRIS |
| **USA** | | | NRC (1999–2004) | NRC (1999–2004) | | | | | |
| | GE – BWR | | | | | | | | |
| **Japan** | GE – ABWR | | JNES (1994–2006) | | JNES (1994–2006) | JNES (drums, no activity, 1994–2006) | IAEA PRIS<br>JNES | JNES<br>Total Dose<br>(1997–2006) | IAEA PRIS<br>JNES |
| | GE – BWR | | | | | | | | |
| **France** | EDF – PWR (N4) | | EU, 1999<br>EU, 2003<br>(1995–2003) | | EU, 1999<br>EU, 2003<br>(1995–2003) | | IAEA PRIS | | IAEA PRIS |
| | EDF – PWR | | | | | | | | |
| **Germany** | Konvoi – PWR | | | | | | | | |
| **Canada** | AECL – Candu | | INFO-0210 | | | | | | IAEA PRIS |

Notes:

| | |
|---|---|
| UNSCEAR | United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) Report: Sources and Effects of Ionizing Radiation 2000; Annex C – Exposures to the Public from Man-made Sources of Radiation. |
| RIFE | Radioactivity in Food and the Environment Reports (Annual reports for years 1995 to 2006) |
| NRC | Nuclear Regulatory Commission; Effluent Database for Nuclear Power Plants |
| JNES | Japan Nuclear Energy Safety Reports: Operational Status of Nuclear Facilities in Japan (Annual reports for years 2004–2007) |
| EU | European Union Reports: Radioactive Effluents from Nuclear Power Stations and Nuclear Fuel Reprocessing Plants in the European Union (1995–1999 Report and 2000–2003 Report) |
| IAEA PRIS | International Atomic Energy Authority; Power Reactor Information System – Online Database |
| INFO-0210 | Radioactive Release Data from Canadian Nuclear Generating Stations 1994 to 2003, INFO-0210 (Revision 12), January 2005, CNSC |

## 3.3 Liquid and gaseous discharge fingerprinting to define the reporting groups

To make possible comparisons between the sourced discharge data, AREVA Risk Management Consulting Ltd developed fingerprints for radioactive liquid discharges and radioactive gaseous discharges. The two fingerprints comprised of the following reporting terms:

i. Radioactive liquid discharge fingerprint:
   - tritium;
   - others.

ii. Radioactive gaseous discharge fingerprint:
   - tritium;
   - iodine-131;
   - noble gases;
   - carbon-14;
   - particulates.

Where the discharge data available covered individual radionuclides, the terms for each relevant individual radionuclide were summed to form a group term.

A number of assumptions were made in developing the fingerprint terms.

i. Where noble gas radionuclides are reported in terms of the individual radionuclides discharged, the sum of the activity for each individual noble gas radionuclide is used to generate a noble gas group term.

   For those power stations that reported noble gas discharges as a group term, it is assumed that this group contains the same individual noble gas radionuclides as the group term generated by the summation process.

ii. Elemental tritium is reported separately for the Darlington Tritium Removal Facility (TRF).

   The Darlington TRF processes wastes from the Darlington reactors and also services other power stations in Canada. It is assumed that the overall tritium discharges will be higher for this power station. Reasonable assumptions were made (detailed later, see Section 4.4.7) for the normalisation of this data.

iii. Where reported data covers an entire nuclear power station, rather than each reactor at a station, it is assumed that the discharges from each reactor are directly proportional to the electrical output from that reactor.

## 3.4 Current information gaps

Although, AREVA Risk Management Consulting Ltd successfully identified viable data sources for liquid and gaseous discharges of radioactivity, there remain a significant number of gaps in the information that is at present publicly available. Furthermore, AREVA Risk Management Consulting Ltd has been unable to identify suitable data sources for a number of the information requirements for this study.

Data on solid waste arising from the treatment of liquid and gaseous discharges has only been identified for Japanese reactors. However, this data is reported as a volume in terms of the number of 200 litre drums of waste produced. The activity or mass of the waste is not known at this time.

AREVA Risk Management Consulting Ltd attempted, with limited success, to source information on abatement techniques used for each reactor design from case studies, and to access occupational dose data arising from use of the abatement techniques.

AREVA Risk Management Consulting Ltd used the IAEA PRIS (IAEA, 2008a) and the UNSCEAR 2000 report (UNSCEAR, 2000) as sources for data relevant to the gross electrical output from the candidate reactors. However, no information source was found for gross thermal output data. AREVA Risk Management Consulting Ltd has estimated the gross thermal output for each reactor based on an efficiency factor calculated for each candidate reactor and the gross electrical output data (see Section 2.4.1).

AREVA Risk Management Consulting Ltd has attempted to gather 10 years' worth of liquid and gaseous discharge data for the candidate reactors. Although liquid and gaseous discharge data is generally available, there are various information gaps for certain years and certain radionuclides for some of the candidate reactors. A summary of all information gaps is provided in the following section (Section 3.4.1).

### 3.4.1 Information gaps

The specific data gaps in this study are as follows:

- pre-1999 carbon-14 data for all Canadian reactors except Point Lepreau;
- post-1997 liquid and gaseous data for Cernavoda-1;
- pre-1997 carbon-14 data for Cernavoda-1;
- liquid and gaseous data for Wolsong-3 and -4;
- post-1997 liquid and gaseous data for Wolsong-1 and -2;
- pre-1997 carbon-14 data for Wolsong-1 and -2;
- pre-2002 gaseous tritium-only data for French candidate reactors;
- pre-2002 gaseous halogen-only data for French candidate reactors;
- pre-2002 gaseous carbon-14 data for French candidate reactors;
- pre-2002 gaseous particulates-only data for French candidate reactors;
- post-2003 liquid data for Civaux-1 and -2 (Civaux-1 and -2 began commercial operation in 2002);
- post-2003 liquid data for Chooz-B1 and Chooz-B2 (Chooz-B1 and -B2 began commercial operation in 2000);
- post-1997 liquid data for Beaver Valley-2;
- post-1993/pre 2001 liquid and gaseous data for Seabrook-1;
- post-1994/pre 2001 liquid and gaseous data for Nine Mile Point-2;

- post-1997 liquid data for Clinton-1;
- post-1997 liquid tritium data for Kashiwazaki-1 to -5;
- carbon-14 data for all candidate reactors in Japan;
- solid waste data for candidate reactors that are predecessors to the EPR, AP1000 and ESBWR designs;
- abatement techniques information for all candidate reactors;
- gross thermal output data for all candidate reactors.

### 3.4.2 Potential information gaps

A number of aspects of discharge data are considered to be potential information gaps because the nuclides do not feature in the NRC Effluents Database as a discharge, but are expected to have been discharged nonetheless. These data points are:

- tritium discharges for Seabrook-1, Beaver Valley-2 for years 2000 to 2004;
- carbon-14 data for PWR candidate reactors in the USA;
- carbon-14 data for BWR candidates in the USA.

# 4. Candidate reactors discharge data

## 4.1 Westinghouse AP1000 predecessors

The following stations have been used in this study as predecessors to the proposed new Westinghouse AP1000 reactor design:

- Seabrook 1;
- Beaver Valley;
- Byron;
- Comanche Peak;
- Sizewell B;
- Takahama.

A tabulated list of the yearly discharges is provided in Appendix D. This section provides short summaries of the reactor sites and lists any trends identified in the data.

### 4.1.1 AP1000 predecessor – Seabrook-1

Seabrook 1 is a Westinghouse PWR located in New Hampshire, USA and operated by Florida Power and Light Company. The reactor started commercial operation in 1990.

#### *4.1.1.1 Trends*

The number of years for which discharge data was available is limited and no trends can be clearly identified.

It is noted, however, that airborne discharges in 2001, 2002 and 2003 are significantly lower than in the early 1990s.

### 4.1.2 AP1000 predecessor – Beaver Valley

The Beaver Valley station consists of two Westinghouse PWRs. It is operated by First Energy Corp and is located in Shippingport, Pennsylvania, USA. The two reactors started commercial operations in 1976 and 1987. The discharge data collated corresponds to both cores.

#### *4.1.2.1 Trends*

A significantly higher quantity of liquid tritium was discharged in 1996. Preliminary research indicates that a possible cause for this increase was the mis-application of leak sealant (NRC Document EA-96-462).

Significantly higher airborne discharges were observed in 1993 and 1996. Preliminary research indicates that a possible cause for this increase in 1993 was the accumulation of gas due to inadequate venting of the charging lines to the volume control tank (NRC Document EA-97-517).

A lower level of airborne discharges was observed during the 1999 to 2004 period. However, discharge data for these years were obtained from the NRC Effluents Database, which does not report any tritium discharges. It is therefore thought that this observed decrease in discharges is mainly due to an absence of tritium data.

### 4.1.3 AP1000 predecessor – Byron

The Byron station consists of two Westinghouse PWRs. It is operated by Exelon Nuclear Company and is located in Byron, Illinois, USA. The two reactors started commercial operations in 1985 and 1987.

Collated data corresponds to both units at Byron.

#### *4.1.3.1 Trends*

The following features and trends were identified, but preliminary research has not identified any explanations:

- a peak in liquid discharges (mainly tritium) in 2004;
- a peak in airborne discharges (mainly noble gases) in 1990;
- a decrease in airborne discharges for the years 2000 to 2004.

It should be noted that an article from Chicago Business News (CBN, 2008) indicates that tritium leaks have been common at three of the nuclear plants managed by Exelon Nuclear Company, including Byron.

### 4.1.4 AP1000 predecessor – Comanche Peak

The Comanche Peak station consists of two Westinghouse PWRs. It is operated by TXU Electric Company and is located in Glen Rose, Texas. The two reactors started commercial operations in 1990 and 1993. The discharge data collated corresponds to both cores.

#### *4.1.4.1 Trends*

A general upward trend in the level of liquid discharges was observed from 1990 to 1997. This increase is thought to be due to an increase in output power after 1993 (the trend was less pronounced following normalisation of the data).

A significantly higher level of noble gases was discharged in the years 1990 to 1992; preliminary research did not identify any causes.

### 4.1.5 AP1000 predecessor – Sizewell B

The Sizewell B station consists of a single PWR based on a Westinghouse design and is located in Leiston, Suffolk, UK. It is operated by British Energy and started commercial operation in 1995.

#### *4.1.5.1 Trends*

A general upward trend in liquid discharges was observed from 1995 to 2003, followed by a sharp decrease in 2004 and then a further upwards trend. This trend is not explained by variations in power output, as the trend is still observed following normalisation of the data.

Peaks in airborne discharges (mainly noble gases) for the years 1998 and 2000 were observed, but preliminary research has not identified any explanations for these peaks.

### 4.1.6 AP1000 predecessor – Takahama

The Takahama station consists of four PWRs and is located in the Oi District in the Fukui Prefecture, Japan. It is operated by Kansai Electric Power Co and the reactors started commercial operations in 1974, 1975, 1984 and 1984. The collated data corresponds to discharges from all four cores.

#### *4.1.6.1 Trends*

A general upward trend in airborne discharges (mainly tritium) was observed from 1990 to 1997 followed by a sharp decrease for 1998 onwards. The sharp decline is due to current information gaps as tritium discharge data was not available from any of the data sources for the years 1998 onwards. It is reasonable to assume that the tritium discharges, during these later years, would be equivalent to previous years.

Normalised liquid discharges follow a sinusoidal trend, with troughs in discharges probably corresponding to the Takahama plant's outages.

Preliminary research indicates that during 1996 and 1997 numerous automatic and manual shutdowns occurred. An International Nuclear Event Scale (INES) of 1 was given for one case in 1996, which is classed as an 'abnormal' event. This event is detailed in the JNES (JNES, 2007) reports.

## 4.2 EDF/Areva EPR predecessors

The following stations have been used in this study as predecessors to the proposed new EDF/Areva EPR design:

- Chooz;
- Civaux;
- Golfech;
- Penly;
- Neckarwestheim;
- Emsland;
- Isar-2.

A tabulated list of the yearly discharges is provided in Appendix E. This section provides short summaries of the reactor sites and lists any trends identified in the data.

### 4.2.1 EPR predecessor – Chooz

The Chooz station consists of two Areva (N4) reactor cores and is located in Chooz, France, close to the border of Belgium. It is operated by EDF and both the reactors became operational during 1997 and started commercial operations during 2000. The discharge data collated corresponds to both cores.

#### *4.2.1.1 Trends*

Normalising the liquid discharges produces a peak in 1998. The other years even out and produce a more consistent discharge trend. In 1998 the electrical output was lower than for other years, contributing to this peak in normalised discharge.

From the available data there appears to be a large decrease in airborne discharges from the 1997 peak to 2002. The peaks in 1996 and 1997 were dominated by the discharges of noble gases, although noble gases were not reported in the European Commission (EC) Radiation Protection 127 document for the years 2002 and onwards. It is assumed that the trend in the discharge of noble gases is consistent with that of the years 1996 and 1997. There is no evidence to suggest that airborne discharges have decreased significantly from 1997.

After normalising the airborne discharges, the peak in 1996 was removed from the normalised result, as there was no power output reported for that year.

### 4.2.2 EPR predecessor – Civaux

The Civaux station, operated by EDF, consists of two Areva (N4) reactor cores and is located in the commune of Civaux at the edge of Vienne River, France. Reactor cores Civaux-1 and Civaux-2 became operational during 1999 and 2000 respectively and both started commercial operations during 2002. The discharge data collated corresponds to both cores.

#### *4.2.2.1 Trends*

Normalising the liquid discharges produces more consistent peaks. This consistent trend shows the apparently low discharge in 1999 is due to a proportionally lower electrical output for that year.

The airborne discharge data is limited. The information gaps for this station are detailed in Section 3.4.

### 4.2.3 EPR predecessor – Golfech

The Golfech station consists of two Areva reactor cores and is located in the commune of Golfech, on the Garonne border between Agen and Toulouse, France. It is operated by EDF and the reactors started commercial operations in 1991 and 1994 respectively. The discharge data collated corresponds to both cores.

#### *4.2.3.1 Trends*

Liquid discharges have been increasing gradually from 1990 to 2006, peaking in 2002. A number of incidents were reported during the years 2001 to 2003, but further investigations are required to ascertain whether these incidents alone are responsible for the increasing discharges.

An over-temperature of the Golfech nuclear power station was reported in 2003, which led to a release into the Garonne River. This event was believed to be due to an incident with the mixture of cooling water. Incidents during the years 2001 and 2002 were also reported, including the loss of a ventilation system in an auxiliary building to non-compliance with the technical specifications for bringing the reactor to operating power. Further investigations are required to draw any conclusions as to whether these incidents affected the discharges for those years.

Normalising the liquid discharges did not highlight any significant trends or unusual discharges. It is therefore fair to assume that the liquid discharges have been linearly proportional to the corresponding electrical power output.

From the available data there appears to be a large decrease in airborne discharges from 1998 to 2001. The peaks before and during 1997 were dominated by the discharges of noble gases, but noble gases have not been reported in the EC Radiation Protection 127 document since 2002. The discharges of noble gases are assumed to be consistent with the trends observed for the years 1996 and 1997. There is no obvious reason to suggest that the airborne discharges have decreased significantly from 1997.

Normalising the airborne discharges produces a peak in 1990. The other years even out and produce a more consistent discharge trend. In 1990 the electric output was lower than for other years, contributing to this peak in normalised discharge. The peak in 1997 also evens out, suggesting that the higher airborne discharges for that year were in fact due to the generation of a higher electrical output.

### 4.2.4 EPR predecessor – Penly

The Penly station consists of two Areva reactor cores and lies in the French municipality of Penly in Normandy, France. It is operated by EDF and the reactors started commercial operations in 1990 and 1992 respectively. The discharge data corresponds to both cores.

#### *4.2.4.1 Trends*

There do not appear to be any significant peaks in liquid discharges that may have resulted from incidents reported during the years studied.

Liquid discharges follow a sinusoidal trend, but this pattern does not appear to be due to refuelling outages as the normalised chart shows a similar trend. Further investigations are required to identify the cause of this sinusoidal trend.

The available data reveal a large decrease in airborne discharges from the 1997 peak to 2002. The peaks in the years up to and including 1997 were dominated by discharges of noble gases. However discharges of noble gases have not been reported in the EC Radiation Protection 127 document since 2002. For the years in which data for discharges of noble gases are not available, it is assumed that the discharges follow the same trend as for the years 1996 and 1997. There is no obvious reason to suggest that airborne discharges have decreased significantly from 1997.

Normalisation of the airborne discharges produces a significant peak in 1990. Normalised data for the other years display a more consistent trend of discharge. In 1990 the electric output was lower than the other years, contributing to this peak in normalised discharge. The raw data peak in 1994 is also flattened following normalisation, suggesting that the higher airborne discharges for that year were in fact due to the production of a higher electrical output.

### 4.2.5 EPR predecessor – Neckarwestheim

The Neckarwestheim station consists of two Areva reactor cores, one of which is a Konvoi design. The station is located in Neckarwestheim, Germany. It is operated by EnBW Kernkraft GmbH and the reactors started commercial operations in 1976 and 1989. The discharge data corresponds to both cores.

#### *4.2.5.1 Trends*

There do not appear to be any significant peaks in liquid discharges that may have resulted from incidents reported during the available years.

There is no clear or accessible explanation for the peaks in airborne discharges during the years 1990 to 1992.

Liquid discharges follow a sinusoidal trend which does not appear to correspond to refuelling outages (as the normalised chart shows a similar trend). Further investigations are required to identify the cause of this sinusoidal trend.

There is a gradual decrease in airborne and normalised discharges. Further investigations are required to investigate the gradual decrease in gaseous discharge. Data for discharges of noble gases were unavailable from 2000 onwards.

### 4.2.6 EPR predecessor – Emsland

The Emsland station consists of an Areva Konvoi reactor core and is located in the district of Emsland, Germany. It is operated by Kernkraftwerke Lippe-Ems GmbH and the reactor started commercial operation in 1988. The discharge data corresponds to the Emsland's core.

#### *4.2.6.1 Trends*

There do not appear to be any significant peaks in liquid discharges that may be attributed to incidents reported during the available years.

Liquid discharges follow a sinusoidal trend, but do not correspond to refuelling outages (as the normalised chart shows a similar trend).

Apart from the peaks in 1998 and 1999, the airborne discharges remained fairly level between 1994 and 2003, although the discharges did increase gradually from 1990 to 1994. Further investigations into the cause of this increase are required. Currently there are no clear or accessible explanations for the peaks in 1998 and 1999.

### 4.2.7 EPR predecessor – Isar-2

The Isar-2 station consists of an Areva Konvoi reactor core and is located next to the Isar River, Germany. It is operated by E.ON Kernkraft GmbH and the reactor started commercial operation in 1988. The discharge data collated corresponds to the Isar-2 core.

#### *4.2.7.1 Trends*

There do not appear to be any significant peaks in liquid discharges that may be attributed to incidents reported during the available years.

There does not appear to be any clear or accessible explanation for the peaks in airborne discharges during the years when the airborne discharges were greater than the predicted normalised EPR discharge.

Liquid discharges follow a sinusoidal trend, which does not appear to correspond to refuelling outages (as the normalised chart shows a similar trend).

Airborne discharges show characteristics of a normal distribution, peaking in 1995 and gradually decreasing until 2003. However, as the normalised data shows a similar trend, this pattern does not appear to be linked with refuelling outages.

Both the normalised and raw liquid and airborne discharges data follow similar trends. It appears that both types of discharge have been increasing then decreasing over time. There is no obvious reason to suggest that the increases and decreases have been proportional to electrical power output.

## 4.3 GE-Hitachi ESBWR predecessors

The following stations have been used in this study as predecessors to the proposed new GE-Hitachi ESBWR reactor design:

- Kashiwazaki-Kariwa;
- Shimane;
- Hamaoka;
- Shika;
- Clinton-1;
- Nine Mile Point.

A tabulated list of the yearly discharges is provided in Appendix F. This section provides short summaries of the reactor sites and lists any trends identified in the data.

### 4.3.1 ESBWR predecessor – Kashiwazaki-Kariwa

The Kashiwazaki-Kariwa station consists of five GE BWRs and two GE-Hitachi ABWRs. The power station is located in the towns of Kaskiwazaki and Kariwa in the Niigata prefecture, on the coast of the Sea of Japan. It is operated by Tokyo Electric Power Co Inc. The discharge data collates all seven of Kashiwazaki-Kariwa's reactor cores. The BWRs started commercial operations in 1985, 1990, 1993, 1994 and 1990. Kashiwazaki-Kariwa-6 and -7 (ABWRs) started commercial operations in 1996 and 1997 respectively.

#### *4.3.1.1 Trends*

A significant observation from the collated data is that liquid discharges have gradually increased since the ABWRs went online during 1996 and 1997. Discharges have often peaked beyond the levels predicted for the ESBWR. A similar trend for airborne discharges might also have been observed, had the airborne data been complete and available.

There is a notable dip in liquid discharges for 2001 and 2002. The lower discharges are thought to stem from a periodical inspection programme, which included the shutting down of a number of the reactor units during these years. The electric energy produced during these years also fell.

In 2003 the normalised discharge peaked above the predicted normalised liquid discharge. Four reactor units were closed for inspection for the whole of 2003 and the overall electrical power produced by the station was lower than usual. The peak in the normalised data suggests that whilst electrical output was lower for 2003, the discharges did not decrease proportionally. JNES (JNES, 2007) did not report any incidents in 2003 that might provide an explanation for this peak. However, during 2002 a defect was found during the periodic inspection of unit 7, one of the three units that remained online during 2003.

Raw airborne discharges appear to increase steeply from 1990 to 1997. However, following normalisation, the discharge rates even out to more consistent values. The steep increase in airborne discharges appears to correspond to a relatively steep increase in electrical output. The airborne discharges appear to be proportional to the electrical power output of the station.

Evidence for one abnormal event at the power station was found. In 1996 during its trial operation, the unit 3 reactor was manually shutdown, as the concentration of iodine in the reactor coolant and the radiation levels in the off gas were showing a tendency to increase. The cause of the event was leakage of a fuel assembly.

### 4.3.2 ESBWR predecessor – Shimane

The Shimane station consists of two GE BWRs and is located in the town of Kashima-chou in the city of Matsue in the Shimane Prefecture. It is operated by Chugoku Electric Power Co Inc and the reactors started commercial operations in 1974 and 1989 respectively. The discharge data collates both of the Shimane power station reactor cores.

#### *4.3.2.1 Trends*

No significant incident is known to have occurred at the plant that might affect discharge levels.

The normalised airborne discharges follow a similar trend to that for the raw discharges data. JNES (JNES, 2007) did not report any incidents between the years 1995 to 2004.

There does not appear to be any distinct trend with the liquid discharges. Some of the observed annual discharge levels are above the predicted ESBWR discharge level, but some are below. An average of the annual discharge data is anticipated to be close to the ESBWR prediction. Troughs in discharges coincide with periods when reactors were shut down for periodical inspections.

As yet, there is no obvious reason for the apparent increase in liquid discharges from 1993 to 1997. However, it should be noted that in 1995 there was an automatic shutdown of unit 2, rated 1 (abnormal event) on the International Nuclear Event Scale.

Normalisation of the airborne discharges did not produce any significant differences in discharge trends, implying that increases or decreases in discharges would not be linearly proportional to the corresponding increase or decrease in electrical power output.

A slight increase in the normalised airborne discharges was observed between 1990 and 1993. Further investigations are required to explain this trend.

### 4.3.3 ESBWR predecessor – Hamaoka

The Hamaoka station consists of four GE BWRs and one GE-Hitachi ABWR and is located in Shizuoka Prefecture, Japan. It is operated by Chubu Electric Power Co Inc. The reactors started commercial operations in 1976, 1978, 1987, 1993 and 2005 respectively. The discharge data collated corresponds to all five of Hamaoka's cores.

#### *4.3.3.1 Trends*

The unit 5 ABWR went online in 2004 and liquid discharges would be expected to be higher than the levels actually observed. Indeed discharges appear to have decreased gradually from 1990 onwards.

JNES (JNES, 2007) did not include any reports of incidents prior to 1994, hence there is no clear explanation for the peak in normalised liquid discharge for 1990. Although, this peak discharge cannot be explained with the available information, the clear trend visible in the graph shows a gradual decrease in the normalised discharge rate over time. However, the peak in discharge does coincide with the introduction of units 3, 4 and 5 and correspondingly an anticipated increase in electrical power output.

The normalised airborne discharge rates follow a similar trend to that for the raw (pre-normalised) data. In 1994 the proportions of noble gases in the discharges appear to be unusual. During this period, the reactor was manually shutdown for a detailed inspection, as an off gas condenser gas monitor and other monitors indicated an increase in radioactivity during a period of rated power operation. The cause of the event was leakage of a fuel assembly, as reported by the JNES (JNES, 2007).

### 4.3.4 ESBWR predecessor – Shika

The Shika station consists of one GE BWR and one GE-Hitachi ABWR and is located in the town of Shika, Ishikawa, Japan. It is operated by Hokuriku Electric Power Co and the reactors started commercial operations in 1993 and 2006 respectively. The discharge data corresponds to both of Shika's cores.

#### *4.3.4.1 Trends*

Shika-2 started commercial operation in 2005 and may have led to the large peaks in liquid discharge observed from 2005 onwards. Prior to 2005 the discharges are judged to be consistent with what might be expected for one BWR reactor core in operation.

In 1999 a criticality accident occurred at unit 1 and was rated 2 (incident) on the International Nuclear Event Scale. However, as AREVA Risk Management Consulting Ltd currently lacks detailed information relevant to this incident, it would be unwise to draw any further conclusions relating this incident to discharges.

The normalised liquid discharges data show the highest peak during 2003. The electrical output for this year was lower than usual. The JNES (JNES, 2007) did not report any incidents that may have contributed to this peak. There does not appear to be any obvious explanation for the low liquid discharges during 1998.

Due to the absence of available airborne discharge data during later years, it has not been possible to relate the liquid and gaseous discharges for every year. There does appear to be a steep increase in non-normalised (raw) and normalised discharges from 1993 to 1995. Further investigations are needed to explain this putative trend.

Normalisation of the airborne discharges did not produce any significant differences in discharge trends. By implication, one can assume that any increase or decrease in discharges is not linearly proportional to an increase or decrease in electrical power output.

### 4.3.5 ESBWR predecessor – Clinton-1

The Clinton-1 station consists of a GE BWR and is located in Illinois, USA. It is operated by Amergen Energy Generating Co and the reactor started commercial operation in 1987. The discharge data related to the single reactor core, Clinton-1.

#### *4.3.5.1 Trends*

The liquid and normalised discharge levels appear consistently below predictions for the two-unit ESBWR design. Information gaps have been detailed previously in Section 3.4.

There does not appear to be an obvious explanation for the high levels of noble gases observed in airborne discharges for 2000. However, in 2000 an incident was reported to the NRC, detailing the failure of two hydramotor pump assemblies. The affected pump assemblies were being installed for the supply air damper in the train control room and the isolation damper in the building housing the fuel for the train standby gas treatment system. This incident may have contributed to the peak in noble gases observed during 2000.

### 4.3.6 ESBWR predecessor – Nine Mile Point-1 and -2

The Nine Mile Point station consists of two GE BWR units and is located approximately five miles northeast of Oswego, New York on the shore of Lake Ontario. It is operated by Nine Mile Point Nuclear Station, LLC and the reactors began commercial operations in 1969 and 1988 respectively. The data collate discharges from both cores at the Nine Mile Point power station.

#### *4.3.6.1 Trends*

The two most obvious peaks in liquid discharges occurred in 1993 and 1995. The NRC website did not report any incidents to the public during 1993. In 1995 two incidents were reported, one a plant shutdown due to problems with the Agastat relays, the other related to inoperable emergency diesel generators. Although there is no evidence that these incidents directly contributed to increased liquid discharges, it is likely that the works undertaken to rectify the incidents may have contributed to the discharges in some fashion.

For example, it was found that the emergency diesel generators were inoperable because the governor coolers were receiving inadequate flow from the jacket cooling water system. Replacements and modifications were installed in the new engines and rigorously tested (perhaps leading to additional discharges) before the reactor was authorised to go back online.

The collated data show that normalised liquid discharges during the years 1993–1995 were above the annual discharge levels predicted for the proposed ESBWR design. Over the period 1990–2006 there is currently no indication of any major incidents that could provide an explanation for the peaks in discharge observed during these years.

In 1991 a ‘site area emergency’ (a classification one level below a ‘general emergency’) was declared at the plant. However, this emergency is not thought to have contributed to liquid or airborne discharges.

In contrast to most of the other BWR power stations included in this study, airborne discharges from the Nine Mile Point power station appear to be dominated by the noble gases. Currently, there is no available explanation for this effect.

Additionally, during the earlier years of the study period (1990–1994), the power station appears to have made significant airborne discharges. However, as with the other BWR stations studied, the airborne discharges from the Nine Mile Point power station are significantly lower than the ESBWR predictions.

Both normalised liquid and airborne discharges have shown a significant decrease from 1994–1995 to 2001. Further investigations are needed to explain this trend.

## 4.4 AECL ACR-1000 predecessors

The following stations have been used in this study as predecessors to the proposed new AECL ACR-1000 reactor design:

- Bruce A;
- Bruce B;
- Gentilly-2;
- Pickering A;
- Pickering B;
- Point Lepreau;
- Darlington.

A tabulated list of the yearly discharges is provided in Appendix G. This section provides short summaries of the reactor sites and lists any trends identified in the data.

Although, the Cernavoda station in Romania was included as a candidate reactor in Table 3.1, no discharge data was collated, as the information was not found to be available.

### 4.4.1 ACR-1000 Predecessor – Bruce A

The Bruce A station consists of four AECL Pressurised Heavy Water Reactors (PHWRs) (units 1–4) and is located in Ontario, Canada on the shore of Lake Huron near the town of Kincardine. It is operated by Bruce Power, and the reactors began commercial operations in 1977, 1977, 1978 and 1979 respectively. The data collates discharges from all four of Bruce A's cores.

It is understood that carbon-14 releases were not reported prior to 1999 (CNSC, 2005).

#### *4.4.1.1 Trends*

A decrease in discharges is observed after 1996, explained by the shutdown of all Bruce A units in 1997 (CNSC, 2005). As part of an extensive recovery programme, Bruce A's operator (Bruce Power) temporarily shut down all Bruce A reactors and all units were held in a guaranteed shutdown state. Unit 4 was restarted in October 2003 and Unit 3 was restarted in January 2004.

The apparent 'gap' in collated data from 1999 to 2002 is in fact a result of the shutdown period. Although the raw data shows discharges for those years, the normalisation process results in zero values, as the electrical power output reported for these years was zero.

The raw airborne discharge data shows a peak during 1994. However, normalisation by electrical output reduces the height of the peak relative to the other years included in the study period. This suggests that the peak observed during 1994 occurred as a direct result of a corresponding increase in electrical power output.

It was also noted that the normalisation process resulted in two peaks in the airborne discharge data, in 1998 and 2003. These two peaks are not thought to have included contributions from any abnormal events, as the raw data between 1998 and 2002 was of a similar magnitude. It is also known that the reactors were shut down during this same period.

### 4.4.2 ACR-1000 predecessor – Bruce B

The Bruce B station consists of four AECL PHWRs (units 5–8) and is located in Ontario, Canada on the shore of Lake Huron near the town of Kincardine. It is operated by Bruce Power and the reactors began commercial operations in 1985, 1984, 1986 and 1987 respectively. The collated data corresponds to all four of Bruce B's cores.

It is understood that carbon-14 releases were not reported prior to 1999/2000 (CNSC, 2005).

#### *4.4.2.1 Trends*

A three-year consecutive decrease in liquid discharges was observed from 1994 to 1996 followed by an increase and then another three-year consecutive decrease. Preliminary research has not identified any causes for this trend.

A peak in liquid discharges was also noted in 2003.

### 4.4.3 ACR-1000 predecessor – Gentilly-2

The Gentilly-2 station consists of one AECL PHWR and is located in Québec, Canada on the St Lawrence River near the city of Trois-Rivières. It is operated by Hydro Quebec and the reactor began commercial operation in 1983.

#### *4.4.3.1 Trends*

A general upward trend was observed from 1997 onwards for liquid discharges and a general downward trend was observed for airborne discharges from 1995 to 1999, followed by an increase in 2000.

These trends were not explained by variations in electrical power output and preliminary research did not identify any causes.

### 4.4.4 ACR-1000 predecessor – Pickering A

The Pickering A station consists of four AECL PHWRs (units 1–4) and is located in Ontario, Canada on the shore of Lake Ontario near the town of Pickering. It is operated by Ontario Power Generation and the reactors began commercial operations in 1971, 1971, 1972 and 1973 respectively. The discharge data corresponds to all four of Pickering A's cores.

#### *4.4.4.1 Trends*

A general downward trend was observed for liquid discharges from 1994 to 2003. The normalised data, however, does not show this same trend.

The apparent ‘gap’ in data from 1998 to 2002 is due to the shutdown of the site over this period (CNSC, 2005). Although there were discharges during those years, the normalisation process results in a zero value because no electrical output was reported for these years.

### 4.4.5 ACR-1000 predecessor – Pickering B

The Pickering B station consists of four AECL PHWRs (units 5–8) and is located in Ontario, Canada on the shore of Lake Ontario near the town of Pickering. It is operated by Ontario Power Generation and the reactors began commercial operations in 1983, 1984, 1985 and 1986 respectively. The discharge data collated corresponds to all four of Pickering B’s cores.

#### *4.4.5.1 Trends*

A general downward trend was observed for liquid discharges from 1994 to 1996 followed by a general upward trend from 1997 to 2001. Discharges were relatively consistent between 2001 and 2003. Preliminary research has not identified any causes for this trend.

### 4.4.6 ACR-1000 predecessor – Point Lepreau

The Point Lepreau station consists of one AECL PHWR and is located in New Brunswick on Point Lepreau, which extends into the Bay of Fundy. It is operated by New Brunswick Electric Power Commission and the reactor began commercial operation in 1983.

#### *4.4.6.1 Trends*

Liquid discharges for the period 1994 to 1997 were typically higher than those for the period 1998 to 2003. The normalised data for liquid discharges indicates that there was a peak in discharges in 1997.

A general downward trend was observed in airborne discharges from 1994 to 2003.

Preliminary research has not identified any probable cause for these trends.

### 4.4.7 ACR-1000 predecessor – Darlington

The Darlington station consists of four AECL PHWRs and a Tritium Removal Facility (TRF). The Darlington station is located in Ontario on the shore of Lake Ontario near the town of Bowmanville. It is operated by Ontario Power Generation and the reactors began commercial operations in 1992, 1990, 1993 and 1993.

#### *4.4.7.1 Trends*

Liquid discharges have been reasonably steady during the period for which data is available.

Airborne discharges for the period 2001 to 2003 were observed to be lower than for the period 1994 to 2000. However, preliminary research has not identified any probable cause for this trend.

# 5. Indicative operational range analysis

## 5.1 AP1000 predecessors

Table 5.1 shows examples of the peaks in discharges identified for the AP1000 predecessor reactors with explanations for the peaks provided where information was available. The peaks were categorised into “abnormal” or “operational”.

### 5.1.1 Summary

Values for the average (statistical mean) discharge and standard deviation were calculated from the discharge data for all AP1000 predecessor reactors for each discharge group. The peaks identified as abnormal (see Table 5.1) were excluded from the average and standard deviation calculations.

A maximum discharge value was calculated by summing the averages (statistical mean) to the standard deviation (used as a measure of the variation in data evident in the collated dataset).

Overall, the prediction for liquid discharges from the AP1000 design is lower than the discharges evident from the predecessor power stations. The prediction for airborne discharges from the AP1000 design is higher than the discharges evident from the predecessor power stations.

#### *5.1.1.1 Liquid tritium discharges*

The average and maximum tritium discharge rates from the dataset studied, excluding abnormal peaks, were found to be:

- Average: 3.03E+00 GBq/Gweh;
- Maximum: 4.61E+00 GBq/Gweh.

The predicted discharge rate from the proposed AP1000 reactor is 3.82E+00 GBq/GWeh which places it between the average and the maximum. It must be noted that this predicted discharge includes a contribution due to conceivable abnormal events.

The collated data also indicates that the discharges of liquid tritium from Sizewell B are greater than those from the other AP1000 predecessor reactor power stations studied.

**Table 5.1 Peaks in discharges for AP1000 predecessors.**

| Peaks | Evidence | Reference | Peak Type |
|---|---|---|---|
| Beaver Valley<br>Liquid tritium, 1996 | Mis-application of leak sealant | NRC Document EA-96-462 | Assumed to be abnormal due to (i) soft evidence and (ii) consistent levels of tritium discharges reported for other years. |
| Beaver Valley<br>Airborne discharge, 1993<br>(mainly noble gases) | Accumulation of gas due to inadequate venting of the charging lines to the volume control tank (NRC Document EA-97-517) | NRC Document EA-97-517 | |
| Beaver Valley<br>Airborne discharge, 1996<br>(mainly noble gases) | Mis-application of leak sealant | NRC Document EA-96-462 | |
| Byron<br>Liquid tritium, 2004 | | | Assumed to be abnormal due to magnitude of discharge. |
| Byron<br>Airborne noble gases, 1990 | | | |
| Comanche Peak<br>Airborne noble gases, 1990–1992 | | | |
| Sizewell B<br>Airborne noble gases, 1998 | | | |
| Sizewell B<br>Airborne noble gases, 2000 | | | |
| Takahama<br>Airborne tritium, 1996–1997 | Numerous automatic and manual shutdowns, including an abnormal event of 1 on the International Nuclear Event Scale (INES). | JNES Reports<br>http://www.jnes.go.jp/english/database/index.html | Abnormal. |

### *5.1.1.2 Other liquid discharges*

The average discharge rate was calculated, but the discharge data for 2000 and 2001 from the Byron reactor power station were excluded. These two data points are not identified as peaks in Table 5.1. However, although the values of total liquid discharge (tritium plus others) for 2000 and 2001 are consistent with the total values for other years, the actual discharge value for other radionuclides are significantly greater than for other years. Therefore, it is concluded that these peaks contain contributions due to abnormal events.

The average and maximum discharge rates for other liquids from the dataset studied, excluding abnormal peaks, were found to be:

- Average: 2.18E-03 GBq/Gweh;
- Maximum: 4.62E-03 GBq/Gweh.

The predicted discharge from the proposed AP1000 reactor is 9.69E-04 GBq/GWeh which is lower than the average. It must be noted that this predicted discharge includes a contribution due to conceivable abnormal events.

### *5.1.1.3 Airborne tritium discharges*

No data points were excluded from the calculations as no airborne tritium peaks were identified as abnormal in Table 5.1.

The average and maximum airborne tritium discharge rates from the dataset studied were found to be:

- Average: 2.12E-01 GBq/Gweh;
- Maximum: 5.38E-01 GBq/Gweh.

The predicted discharge from the proposed AP1000 reactor is 1.32E+00 GBq/GWeh which is higher than the average and maximum values. It must be noted that this predicted discharge includes a contribution due to conceivable abnormal events.

### *5.1.1.4 Airborne noble gas discharges*

With the exclusion of the peaks identified as abnormal in Table 5.1, the average and maximum noble gas discharges from the dataset studied were found to be:

- Average: 2.80E-01 GBq/GWeh;
- Maximum: 6.96E-01 GBq/GWeh.

The predicted discharge from the proposed AP1000 reactor is 4.17E+01 GBq/GWeh which is higher than the average and maximum values. It must be noted that this predicted discharge includes a contribution due to conceivable abnormal events.

### *5.1.1.5 Airborne iodine-131 discharges*

In order to calculate the average discharge resulting from operational discharges only, an average was computed which excluded discharge data for Beaver Valley for 2003. This data point was not identified as a peak in Table 5.1. However, although the value for total airborne discharges for 2003 is consistent with the total value for other years, the actual discharge value for iodine-131 is significantly greater than for other years. Therefore, it is concluded that the discharges for 2003 contain contributions due to probable abnormal events that contributed to an increase in the discharge of iodine-131 for that year.

The average and maximum iodine-131 discharges from the dataset studied, excluding abnormal peaks, were found to be:

- Average: 1.35E-05 GBq/GWeh;
- Maximum: 5.69E-05 GBq/GWeh.

The predicted discharge from the proposed AP1000 reactor is 4.54E-04 GBq/GWeh which is higher than the average and maximum values. It must be noted that this predicted discharge includes a contribution due to conceivable abnormal events.

#### *5.1.1.6 Airborne particulate discharges*

In order to calculate the average discharge resulting from operational discharges only, an average was computed which excluded the peaks identified as abnormal in Table 5.1 (i.e. Beaver Valley, 1993). In addition, the data point for Beaver Valley in 1995 was also excluded from the calculations as it was significantly higher than the discharge for other years. This was not initially obvious from the total airborne discharge data as the airborne particulates accounted for a relatively small fraction of the total airborne discharge value.

The average and maximum airborne particulate discharges from the dataset studied, excluding abnormal peaks were found to be:

- Average: 2.72E-06 GBq/GWeh;
- Maximum: 8.17E-06 GBq/GWeh.

The predicted discharge from the proposed AP1000 reactor is 1.79E-04 GBq/GWeh which is higher than both the average and maximum values. It must be noted that this predicted discharge includes a contribution due to conceivable abnormal events.

#### *5.1.1.7 Airborne carbon-14 discharges*

The average discharge of carbon-14 resulting from normal operations was computed and is given below. Carbon-14 discharge data for AP1000 predecessors was only available for Sizewell B.

The average and maximum carbon-14 discharges from the dataset studied were found to be:

- Average: 1.80E-02 GBq/GWeh;
- Maximum: 2.66E-02 GBq/GWeh.

The predicted discharge from the proposed AP1000 reactor is 2.76E-02 GBq/GWeh which is higher than both the average and maximum values. It must be noted that this predicted discharge includes a contribution due to conceivable abnormal events.

## 5.2 EPR predecessors

Table 5.2 shows examples of the peaks in discharges identified for the EPR predecessor reactors with explanations for the peaks provided where information was available. The peaks were categorised as “abnormal” or “operational”.

### 5.2.1 Summary

Values for the average (statistical mean) discharge and standard deviation were calculated from the discharge data for all EPR predecessor reactors for each discharge group. The peaks identified as abnormal in Table 5.2 were excluded from the average and standard deviation calculations.

A maximum value was calculated by summing the average (statistical mean) to the standard deviation (used as a measure of the variation in data evident in the collated dataset).

Overall, the prediction for liquid discharges from the EPR design is higher than the discharges reported for the predecessor power stations. The prediction for airborne discharges from the EPR design is similar to the discharges reported for the predecessor power stations.

#### *5.2.1.1 Liquid tritium discharges*

In order to calculate the average discharge under normal operational conditions, the average (statistical mean) was calculated, excluding the peaks identified as abnormal in Table 5.2.

The average and maximum tritium discharges from the dataset studied were found to be:

- Average: 1.68E+00 GBq/GWeh;
- Maximum: 2.43E+00 GBq/GWeh.

The predicted discharge from the proposed EPR reactor is 3.58E+00 GBq/Gweh, which is higher than these average and maximum values.

**Table 5.2 Peaks in discharges for EPR predecessors.**

| Peaks | Evidence | Reference | Peak Type |
|---|---|---|---|
| Chooz<br>Liquid tritium, 1998 | Peak only observed after normalisation[a] | PRIS database. | Assumed to be operational as no evidence found to suggest an abnormal event |
| Chooz<br>Airborne noble gases, 1996 and 1997 | Due to information gaps, the discharges in 1996 and 1997 appear as peaks | | Operational |
| Golfech<br>Liquid tritium, 2001–2003 | | | Assumed to be operational as no evidence found to suggest an abnormal event |
| Golfech<br>Airborne noble gases, 1990 | Peak only observed after normalisation[a] | PRIS database. | Operational |
| Penly<br>Other liquids, 1990 | Peak is only observed after normalisation[a] | PRIS database. | Operational |
| Penly<br>Airborne noble gases, 1990 | Peak is only observed after normalisation[a] | PRIS database. | Operational |
| Neckarwestheim<br>Airborne noble gases, 1990–1992 | | | Assumed to be operational as no evidence found to suggest an abnormal event |
| Emsland<br>Airborne tritium and noble gases, 1998 and 1999 | | | Assumed to be operational as no evidence found to suggest an abnormal event |

Notes: [a] A post-normalisation peak indicates that relatively smaller amounts of energy were produced during that year but discharges were similar to previous years during which the reactor was shut down.

### *5.2.1.2 Other liquid discharges*

The average discharge for other liquids during the normal operation of the reactors was calculated by excluding the peaks identified as abnormal in Table 5.2.

The collated data for Penly shows a peak in 1990. This is seen as an operational peak rather than an abnormal discharge. The discharges of other liquid discharges from Penly are small in comparison to this station's its tritium discharge. However, Penly's discharges of other liquids are considerably higher than those from other predecessor reactors.

The average and maximum discharge of other liquids from the dataset studied were found to be:

- Average: 6.85E-05 GBq/GWeh;
- Maximum: 2.04E-04 GBq/GWeh.

The predicted discharge from the proposed EPR reactor is 1.62E-03 GBq/Gweh, which is higher than these average and maximum values.

### *5.2.1.3 Airborne tritium discharges*

None of the data points were excluded from the calculations, as no abnormal airborne tritium peaks were identified in the dataset (see Table 5.2).

The average and maximum tritium discharges from the dataset studied were found to be:

- Average: 8.50E-02 GBq/GWeh;
- Maximum: 1.44E-01 GBq/GWeh.

The predicted discharge from the proposed EPR reactor is 3.42E-02 GBq/Gweh, which is lower than the calculated average for the predecessor reactors.

### *5.2.1.4 Airborne noble gas discharges*

None of the data points were excluded from the calculations as no abnormal airborne noble gas discharge peaks were identified in the dataset (see Table 5.2).

The average and maximum noble gas discharges from the dataset studied were found to be:

- Average: 4.81E-01 GBq/GWeh;
- Maximum: 1.20E+00 GBq/GWeh.

The predicted discharge from the proposed EPR reactor is 5.50E-02 GBq/Gweh, which is lower than the calculated average for the predecessor reactors.

### *5.2.1.5 Airborne iodine-131 discharges*

None of the data points were excluded from the calculations as no abnormal airborne iodine-131 peaks were identified in the dataset as (see Table 5.2).

The average and maximum iodine-131 discharges from the dataset studied were found to be:

- Average: 1.05E-06 GBq/GWeh;
- Maximum: 3.00E-06 GBq/GWeh.

The predicted discharge from the proposed EPR reactor is 1.57E-06 GBq/GWeh, which places it between the average and maximum values.

### 5.2.1.6 *Airborne particulate discharges*

The average and maximum discharges of airborne particulates calculated from the dataset studied were found to be:

- Average: 1.48E-07 GBq/GWeh;
- Maximum: 3.80E-07 GBq/GWeh.

The predicted discharge from the proposed EPR reactor is 2.75E-07 GBq/GWeh, which places it between the average and the maximum.

### 5.2.1.7 *Airborne carbon-14 discharges*

The average and maximum carbon-14 discharges from the dataset studied was found to be:

- Average: 3.07E-02 GBq/GWeh;
- Maximum: 4.46E-02 GBq/GWeh.

The predicted discharge from the proposed EPR reactor is 2.41E-02 GBq/GWeh, which is less that the average calculated for the predecessor reactors.

## 5.3 ESBWR predecessors

Table 5.3 shows examples of the peaks in discharges identified for the ESBWR predecessor reactors. These peaks are analysed relative to other peaks and are addressed in the calculations of the average and maximum discharges.

### 5.3.1 Summary

Values for the average (statistical mean) discharge and standard deviation were calculated from the discharge data for all ESBWR predecessor reactors for each discharge group. The peaks identified as abnormal in Table 5.3 were excluded from the average and standard deviation calculations.

A maximum value was calculated by summing the average (statistical mean) to the standard deviation (used as a measure of the variation in data evident in the collated dataset).

Overall, the predictions for liquid and airborne discharges from the ESBWR design are similar to the AP1000 design. The prediction for liquid discharges is within the range of discharges evident from the studied predecessor reactors. However, the predictions for airborne discharges are greater than the discharges evident from the predecessors.

#### *5.3.1.1 Liquid tritium discharges*

The average discharge resulting from operational discharges only was calculated by excluding the discharge data for Hamaoka for 1990 and Shimane for 1996. It is assumed that the peaks for liquid tritium discharges at these stations in these years were a result of abnormal events (the discharges were significantly higher in comparison to other years). These values have been excluded from the average and standard deviation calculations.

The average and maximum tritium discharges from the dataset studied were found to be:

- Average: 4.04E-02 GBq/GWeh;
- Maximum: 7.29E-02 GBq/GWeh.

The predicted discharge from the proposed ESBWR reactor is 3.79E-02 GBq/Gweh, which is lower than the average discharge calculated for these predecessor reactors.

**Table 5.3 Peaks in discharges for ESBWR predecessors.**

| Peaks | Evidence | Reference | Peak Type |
|---|---|---|---|
| Kashiwazaki-Kariwa<br>Liquid tritium, 2003 | Four reactor units out of seven were closed down for periodic inspection, thus the power output was lower for 2003 | JNES webpage | Operational |
| Shimane<br>Liquid tritium, 1996 | | | Assumed to be abnormal due to magnitude of discharge |
| Hamaoka<br>Liquid tritium, 1990 | | | Assumed to be abnormal due to magnitude of discharge |
| Shika<br>Liquid tritium, 2003 and 2004 | Peak is only observed after normalisation[a] | PRIS database | Potentially abnormal due to magnitude of discharge, but 2005 and 2006 consistent with 2003, 2004. Therefore assumed to be operational. |
| Clinton-1<br>Airborne noble gases, 2000 | Two hydramotor pump assemblies (one belonging to the gas treatment system fuel building) had to be replaced | NRC webpage | Abnormal |

Notes: [a] A post-normalisation peak indicates that relatively smaller amounts of energy were produced during that year but discharges were similar to previous years during which the reactor was shut down.

### 5.3.1.2 *Other liquid discharges*

The average discharge of other liquids under normal operating conditions was calculated by excluding the discharge data for Nine Mile Point for 1992. This data point was not identified as a peak in Table 5.3. However, although the value of total liquid discharge (tritium plus others) for 1992 is consistent with the total values for other years, the actual discharge value for other radionuclides is significantly greater than for other years. It therefore appears that this peak contains contributions due to abnormal events. This value has been excluded from the average and standard deviation calculations.

The average and maximum discharges of other liquids from the dataset studied were found to be:

- Average: 1.37E-04 GBq/GWeh;
- Maximum: 3.25E-04 GBq/GWeh.

The predicted discharge from the proposed ESBWR reactor is 2.65E-04 GBq/Gweh, which places it in between the average and the maximum values.

### 5.3.1.3 *Airborne tritium discharges*

No data points have been excluded from the calculations, as no abnormal airborne tritium peaks were identified from the dataset (see Table 5.3). Although, the majority of discharge values from the Nile Mile Point power station lie above the maximum line they are not judged as abnormal, but reflect the operational discharges at that particular power station.

The average and maximum airborne tritium discharges from the dataset studied were found to be:

- Average: 6.53E-02 GBq/GWeh;
- Maximum: 1.49E-01 GBq/GWeh.

The predicted discharge from the proposed ESBWR reactor is 2.05E-01 GBq/Gweh, which is higher than the average and maximum.

### 5.3.1.4 *Airborne noble gas discharges*

In order to calculate the average operational discharge, the discharge data for Clinton-1 for 2000 was excluded. This data point is identified as an abnormal event peak in Table 5.3.

Although, many of the discharge values from the Nile Mile Point power station lie above the maximum line they are not judged as abnormal, but reflect the operational discharges at that particular power station.

The average and maximum noble gas discharges from the dataset studied were found to be:

- Average: 3.92E-01 GBq/GWeh;
- Maximum: 1.01E+00 GBq/GWeh.

The predicted discharge from the proposed ESBWR reactor is 1.12E+01 GBq/GWeh, which is higher than the average and maximum.

#### 5.3.1.5 Airborne iodine-131 Discharges

No data points have been excluded from the calculations as no airborne iodine-131 peaks were identified as being abnormal in Table 5.3.

Although the majority of the discharge values from the Nile Mile Point power station lie above the maximum line, they are not judged abnormal to operational discharges at that power station.

The average and maximum iodine-131 discharges from the dataset studied were found to be:

Average: 2.82E-06 GBq/GWeh

Maximum: 8.06E-06 GBq/GWeh

The predicted discharge from the proposed ESBWR reactor is 1.10E-03 GBq/GWeh, which is higher than the average and maximum.

#### 5.3.1.6 Airborne particulate discharges

The average airborne particulates discharge value under normal operating conditions was calculated excluding the discharge data from Clinton-1 for 2004. This data point was not identified as a peak in Table 5.3 above. However, although the value of total airborne discharge for 2004 is consistent with the total values for other years, the actual discharge value for airborne particulates is significantly greater than for other years. Therefore, it is concluded that this peak contains contributions due to abnormal events. For this reason the value has been excluded from the average and standard deviation calculations.

The average and maximum airborne particulate discharges from the dataset studied were found to be:

- Average: 3.42E-05 GBq/GWeh;
- Maximum: 1.86E-04 GBq/GWeh.

The predicted discharge from the proposed EPR reactor is 3.59E-04 GBq/GWeh, which is higher than the average and maximum values.

#### 5.3.1.7 Airborne carbon-14 discharges

No data available.

## 5.4 ACR-1000 predecessors

Table 5.4 below shows examples of the peaks in discharges identified for the ACR-1000 predecessor reactors.

### 5.4.1 Summary

An average and standard deviation was calculated for the discharges from all ACR-1000 predecessor reactors for each discharge group. The peaks identified as abnormal in Table 5.4 were excluded from the average and standard deviation calculations.

A maximum value was calculated by summing the average (statistical mean) to the standard deviation (used as a measure of the variation in data evident in the collated dataset).

Overall, the predictions for both liquid and airborne discharges from the ACR-1000 design are lower than the discharges evident from the predecessor power stations studied.

#### *5.4.1.1 Liquid tritium discharges*

The average and maximum liquid tritium discharges from the dataset studied were found to be:

- Average: 3.74E+01 GBq/GWeh;
- Maximum: 7.47E+01 GBq/GWeh.

The predicted discharge from the proposed ACR-1000 reactor is 1.26E+01 GBq/GWeh, which is lower than the average calculated for the predecessors. It must be noted that this predicted discharge includes a contribution due to conceivable abnormal events.

The collated data also indicate that the liquid tritium discharges from Gentilly-2 are higher than the liquid tritium discharges from the other ACR-1000 predecessor reactor power stations, included in this study.

**Table 5.4 Peaks in discharges for ACR-1000 predecessors.**

| Peaks | Evidence | Reference | Peak Type |
|---|---|---|---|
| Bruce B<br>Liquid tritium, 2003 | Peak is only observed after normalisation[a] | | Operational |
| Point Lepreau<br>Liquid tritium, 1997 | | | Assumed to be operational as no evidence found to suggest an abnormal event and increase compared to previous years not significant enough. |

Notes: [a] A post-normalisation peak indicates that relatively smaller amounts of energy were produced during that year but discharges were similar to previous years during which the reactor was shut down.

#### *5.4.1.2 Other liquid discharges*

The average liquid discharge value under normal operating conditions was calculated, excluding discharge data from Bruce A for 1998. This data point was not identified as a peak in Table 5.4. However, although the value of total liquid discharges (tritium plus other liquids) for 1998 is consistent with the total values for other years, the actual discharge value for other liquids is significantly greater than for other years. Therefore, it is concluded that this peak contains contributions due to abnormal events.

Although the discharge from Gentilly-2 in 1995 may appear to be a peak, it has not been judged to contain a contribution from any abnormal events, as the discharge is not judged to be significantly greater than discharges from Gentilly-2 for other years.

The average and maximum discharges for other liquids from the dataset studied, excluding abnormal peaks were found to be:

- Average: 2.03E-03 GBq/GWeh;
- Maximum: 4.40E-03 GBq/GWeh.

The predicted discharge from the proposed ACR-1000 reactor is 1.47E-03 GBq/GWeh, which is lower than the average calculated for the predecessor reactors. It must be noted that this predicted discharge includes a contribution due to conceivable abnormal events.

#### *5.4.1.3 Airborne tritium discharges*

No data points have been excluded from the calculations, as no abnormal airborne tritium peaks were identified in the dataset (see Table 5.4).

The average and maximum airborne tritium discharges from the dataset studied, excluding abnormal peaks were found to be:

- Average: 3.68E+01 GBq/GWeh;
- Maximum: 7.80E+01 GBq/GWeh.

The predicted discharge from the proposed ACR-1000 reactor is 5.26E+00 GBq/GWeh, which places it between the average and maximum values. It must be noted that this predicted discharge includes a contribution due to conceivable abnormal events.

#### *5.4.1.4 Airborne noble gas discharges*

No data points have been excluded from the calculations, as no abnormal airborne noble gas discharge peaks were identified in the dataset (see Table 5.4).

The average and maximum airborne noble gas discharges from the dataset studied, excluding abnormal peaks were found to be:

- Average: 1.44E+01 GBq/GWeh;
- Maximum: 5.68E+01 GBq/GWeh.

The predicted discharge from the proposed ACR-1000 reactor is 1.68E+00 GBq/GWeh, which is less than the average value calculated for the predecessor reactors. It must be noted that this predicted discharge includes a contribution due to conceivable abnormal events.

#### *5.4.1.5 Airborne iodine-131 discharges*

No data points have been excluded from the calculations, as no abnormal airborne iodine peaks were identified in the dataset (see Table 5.4).

The average and maximum airborne iodine-131 discharges from the dataset studied, excluding abnormal peaks were found to be:

- Average: 5.66E-06 GBq/GWeh;
- Maximum: 1.67E-05 GBq/GWeh.

The predicted discharge from the proposed ACR-1000 reactor is 8.42E-07 GBq/GWeh, which is less than the average value. It must be noted that this predicted discharge includes a contribution due to conceivable abnormal events.

#### *5.4.1.6 Airborne particulate discharges*

The average and maximum airborne particulate discharges from the dataset studied, excluding abnormal peaks were found to be:

- Average: 1.24E-05 GBq/GWeh;
- Maximum: 6.59E-05 GBq/GWeh.

Predicted discharges for the particulates group were not available.

#### *5.4.1.7 Airborne carbon-14 discharges*

The calculation for the average discharge for carbon-14 occurring during normal operations excluded discharge data from Pickering B for 2000. This data point was not identified as a peak in Table 5.4 because it did not contribute to an overall peak in total airborne discharges. However, a significant peak in carbon-14 discharges from Pickering B during 2000 is evident when compared against carbon-14 discharges from this reactor during other years. This discharge is sufficiently high to suggest that it may contain contributions due to abnormal events. The carbon-14 discharge from Pickering B for 2000 is therefore excluded from the calculations.

The average and maximum airborne carbon-14 discharges from the dataset studied, excluding abnormal peaks were found to be:

- Average: 1.81E-01 GBq/GWeh;
- Maximum: 4.17E-01 GBq/GWeh.

The predicted discharge from the proposed ACR-1000 reactor is 2.95E-02 GBq/GWeh, which is lower than the calculated average value. It must be noted that this predicted discharge includes a contribution due to conceivable abnormal events.

# 5.5 Reactor discharge performance

## 5.5.1 Operational performance

A comparison was made between the mean and standard deviation values calculated from the discharge data for the predecessor power stations included in this study. This step enables a comparison of the overall performance of the predecessors for each of the four proposed designs. The mean and standard deviation values obtained for each of the radionuclide discharge groups studied for the four predecessor groups are shown in Table 5.5 to Table 5.11.

**Table 5.5 Comparison of liquid tritium discharges in GBq/GWeh.**

| Reactor Class | Mean | Standard Deviation |
|---|---|---|
| AP1000 | 3.03E+00 | 1.58E+00 |
| EPR | 1.68E+00 | 7.44E-01 |
| ESBWR | 4.04E-02 | 3.25E-02 |
| ACR-1000 | 3.52E+01 | 3.58E+01 |

**Table 5.6 Comparison of other liquid discharges in GBq/GWeh.**

| Reactor Class | Mean | Standard Deviation |
|---|---|---|
| AP1000 | 2.18E-03 | 2.44E-03 |
| EPR | 6.85E-05 | 1.35E-04 |
| ESBWR | 1.37E-04 | 1.88E-04 |
| ACR-1000 | 1.80E-03 | 2.32E-03 |

**Table 5.7 Comparison of airborne tritium discharges in GBq/GWeh.**

| Reactor Class | Mean | Standard Deviation |
|---|---|---|
| AP1000 | 2.12E-01 | 3.26E-01 |
| EPR | 8.50E-02 | 5.91E-02 |
| ESBWR | 6.53E-02 | 8.36E-02 |
| ACR-1000 | 4.05E+01 | 4.09E+01 |

**Table 5.8 Comparison of airborne noble gas discharges in GBq/GWeh.**

| Reactor Class | Mean | Standard Deviation |
|---|---|---|
| AP1000 | 2.80E-01 | 4.16E-01 |
| EPR | 4.81E-01 | 7.16E-01 |
| ESBWR | 3.92E-01 | 6.19E-01 |
| ACR-1000 | 1.50E+01 | 4.07E+01 |

**Table 5.9 Comparison of airborne iodine-131 discharges in GBq/GWeh.**

| Reactor Class | Mean | Standard Deviation |
|---|---|---|
| AP1000 | 1.35E-05 | 4.34E-05 |
| EPR | 1.05E-06 | 1.95E-06 |
| ESBWR | 2.82E-06 | 5.24E-06 |
| ACR-1000 | 5.61E-06 | 1.10E-05 |

**Table 5.10 Comparison of airborne particulate discharges in GBq/GWeh.**

| Reactor Class | Mean | Standard Deviation |
|---|---|---|
| AP1000 | 2.72E-06 | 5.45E-06 |
| EPR | 1.48E-07 | 2.32E-07 |
| ESBWR | 3.42E-05 | 1.51E-04 |
| ACR-1000 | 1.08E-05 | 5.02E-05 |

**Table 5.11 Comparison of airborne carbon-14 discharges in GBq/GWeh.**

| Reactor Class | Mean | Standard Deviation |
|---|---|---|
| AP1000 | 1.80E-02 | 8.52E-03 |
| EPR | 3.07E-02 | 1.38E-02 |
| ESBWR | | |
| ACR-1000 | 1.81E-01 | 2.36E-01 |

The best reactor predecessor performer is highlighted in each table. Table 5.12 shows the best performers for each radionuclide group.

**Table 5.12 Best performers for each radionuclide discharge group.**

| Radionuclide Group | Best Performer |
|---|---|
| Liquid tritium | ESBWR |
| Other liquid | EPR |
| Airborne tritium | ESBWR |
| Airborne noble gas | AP1000 |
| Airborne iodine-131 | EPR |
| Airborne particulate | EPR |
| Airborne carbon-14 | AP1000 |

As can be seen from Table 5.12, with the exception of the predecessors to the ACR-1000, each design performs best on different discharge groups.

When the means of the total discharge (i.e. the mean of the sum of discharge for all of the above radionuclide groups) were compared[1], it was found that ESBWR predecessors were the best performers whilst the ACR-1000 predecessors gave the highest mean discharge. The mean discharge from each reactor class is shown in Table 5.13.

---

[1] It must be noted that the mean discharge calculations exclude any data believed to have been caused by accidents or circumstances outside of normal operations.

**Table 5.13 Comparison of total mean discharge from predecessor reactors.**

| Reactor Class | Mean | Standard Deviation |
|---|---|---|
| AP1000 | 3.54E+00 | 2.33E+00 |
| EPR | 2.28E+00 | 1.53E+00 |
| ESBWR | 4.98E-01 | 7.35E-01 |
| ACR-1000 | 9.09E+01 | 1.18E+02 |

Figure 5.1 shows the mean discharge from the predecessors for each of the four new proposed designs.

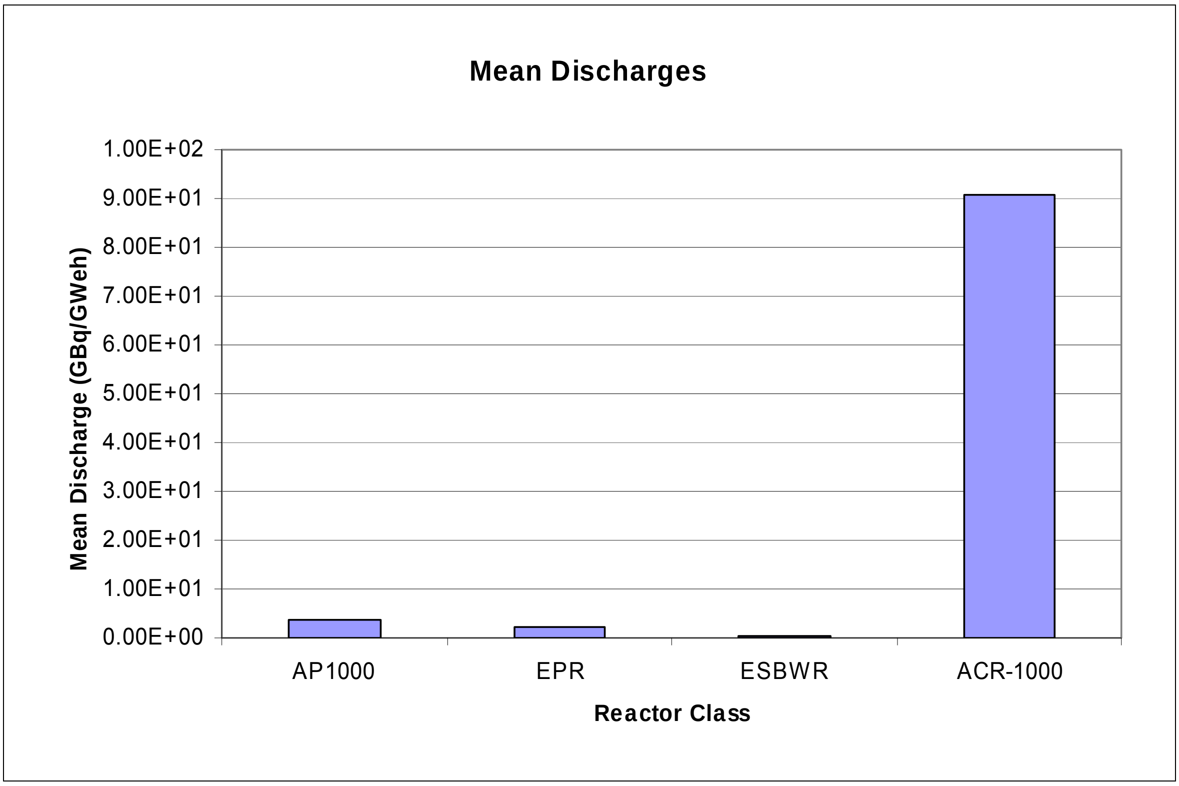

**Figure 5.1 Mean discharge comparison.**

### 5.5.2 Comparison of predicted discharges

The predicted discharges for each of the four new designs are detailed in Table 5.14.

**Table 5.14 Comparison between predicted discharges.**

| Predicted discharge | ACR-1000[a] | ESBWR[b] | EPR[c] / Max release | AP1000[d] |
|---|---|---|---|---|
| **Gaseous** | | | | |
| Tritium | 100000 GBq | 2800 GBq | 500 / 3000 GBq | 12950 GBq |
| Carbon-14 | 560 GBq | 354 GBq | 350 / 900 GBq | 270.1 GBq |
| Noble Gases | 32000 GBq-MeV/a | 153000 GBq | 800 / 22500 GBq | 408258 GBq |
| Iodine-131 | 0.016GBq | 15.1 GBq | 0.0228 / 0.182 GBq | 4.44 GBq |
| Particulates | N/a | 4.9 GBq | 0.004 / 0.340 GBq | 1.75 GBq |
| Gaseous total | 132560 GBq | 156174 GBq | 1650 / 26400 GBq | 421000 GBq |
| **Liquid** | | | | |
| Tritium | 240000 GBq | 518 GBq | 52000 / 75000 GBq | 37370 GBq |
| Other | 28 GBq | 3.63 GBq | 23.6 / 105.05 GBq | 9.48 GBq |
| Liquid total | 240028 GBq | 521.63 GBq | 52023.60 / 75105.05 GBq | 37379 GBq |
| **Total** | | | | |
| Gaseous + Liquid total | 372588 GBq | 156696 GBq | 53674 / 101505 GBq | 458379 GBq |

Notes:

[a] Two-unit ACR-1000 annual average normal release. Assuming a Tritium Removal Facility (TRF) will be operating (on-site or off-site) within three years of the reactor in-service date to reduce tritium activity in moderator water (<0.5 TBq/kg). Also note that particulates have not been included in the total discharge.

[b] The methodology of NUREG-0016 was used in determining the annual airborne release values in the above table. The BWR-Gale code was used in determining the annual liquid release values.

[c] The expected performance of the EPR. The estimated average release is calculated by applying design-based improvements to reference values derived from experience feedback. The maximum release values include a margin based on expected performance values so as to cover all normal operating conditions, e.g. small leaks.

[d] The release totals include an adjustment of 0.16 Ci/yr added by PWR-GALE code to account for anticipated operational occurrences, such as operator error, that result in unplanned releases.

# 6. Conclusions

One of the initial objectives of this study was to identify whether there is evidence of any clear relationship between the power output of a reactor and radioactive discharges into the environment. From the discharge data available, no simple, clear or easily explained relationship is apparent.

It might be logical to assume that an increase in the power output of a reactor (i.e. working the reactor harder), would result in an increase in discharges into the environment. However, this was not always found to be the case. Instead, the majority of candidate reactors in question displayed a mix of the following characteristics:

i. No correlation
The radioactive discharge did not show any correlation with the increased or decreased reactor power station output.

ii. Proportional relationship
The radioactive discharge increased as a result of an increase in reactor power station output. There is some evidence that a proportional relationship exists between the level of radioactive discharge and power station output.

iii. Abnormal events
The level of radioactive discharge increased because of an abnormal event, either identified or unidentified. Subjective judgement was used to classify some high discharge values as abnormal, based predominantly on a comparison with discharges during other years at the same power station. Efforts were made to find evidence of abnormal events that might help to support the judgements made. Further investigations will be required to develop this process.

## 6.1 No correlation

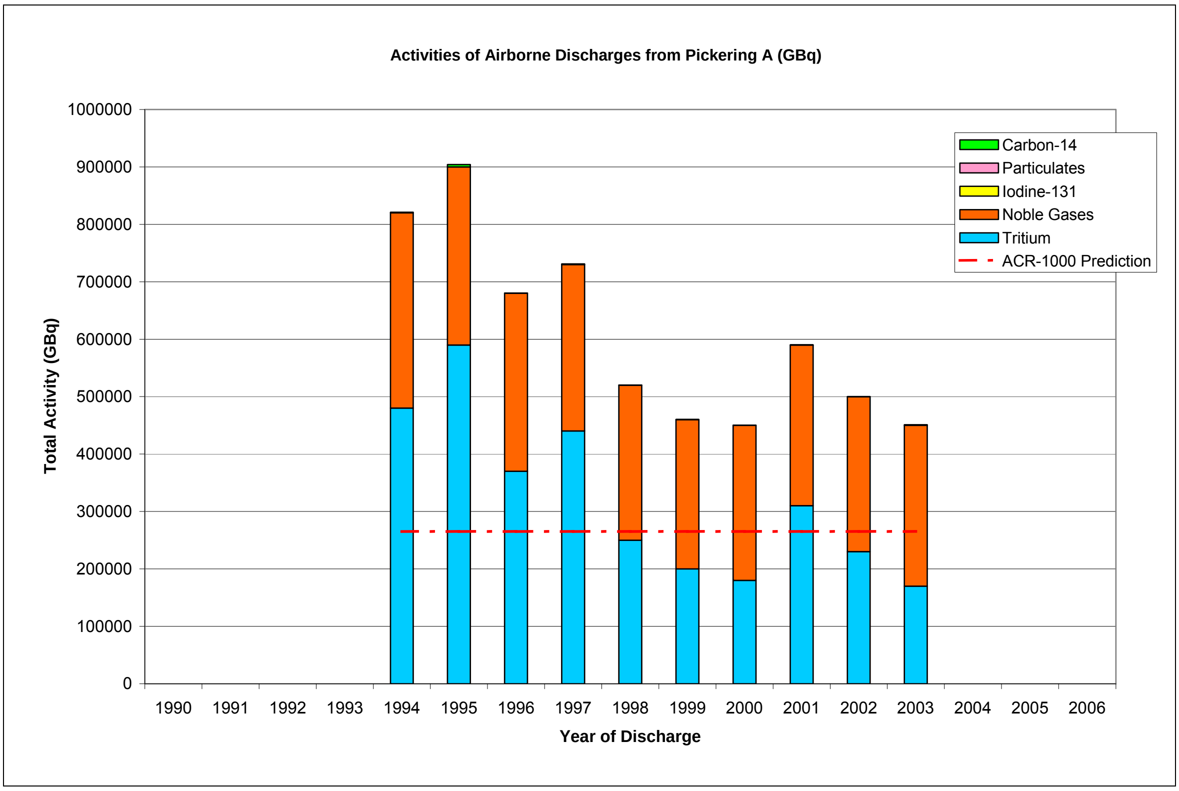

**Figure 6.1 Total activity of airborne discharges from Pickering A in GBq/a.**

Figure 6.1 shows the airborne discharges from Pickering A, an ACR-1000 predecessor, which was shut down during the period 1997 to 2003. Despite the fact that the power output from the reactor power station during that period was zero, the level of discharge was comparable to other years when power was generated. This indicates that the correlation between power output and discharge is limited.

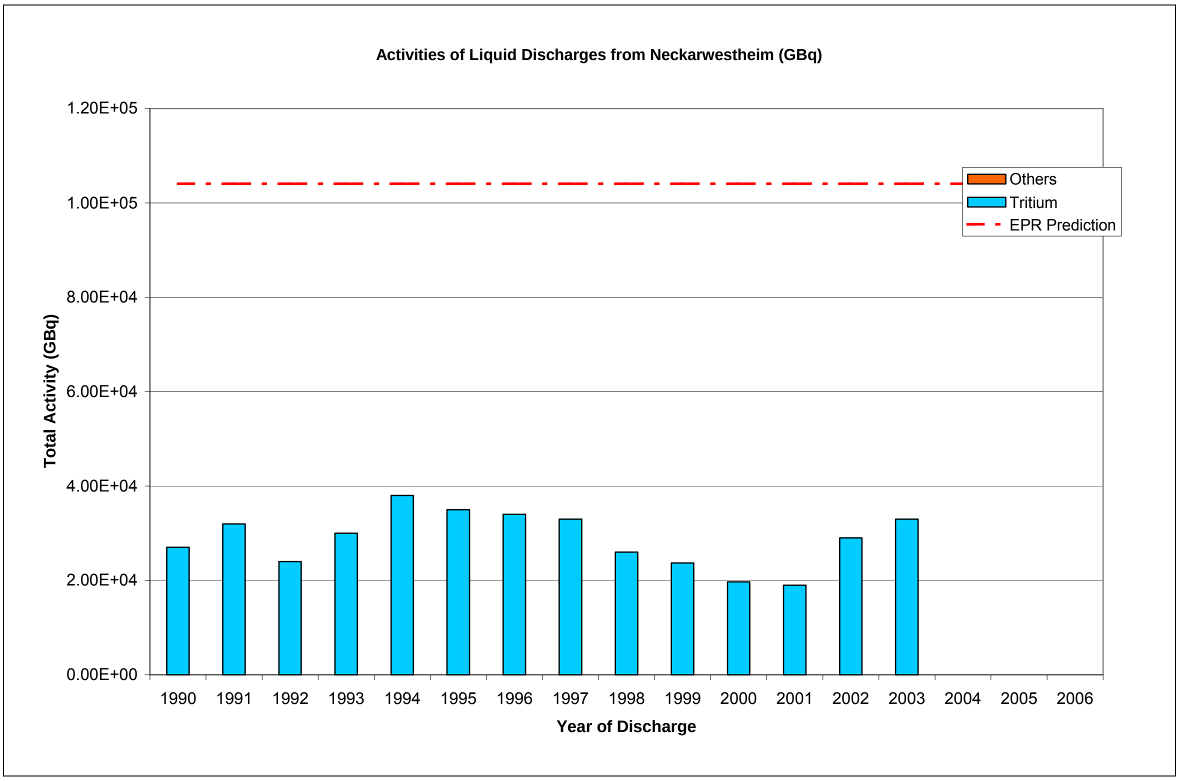

Figure 6.2 Total activity of liquid discharges from Neckarwestheim in GBq/a.

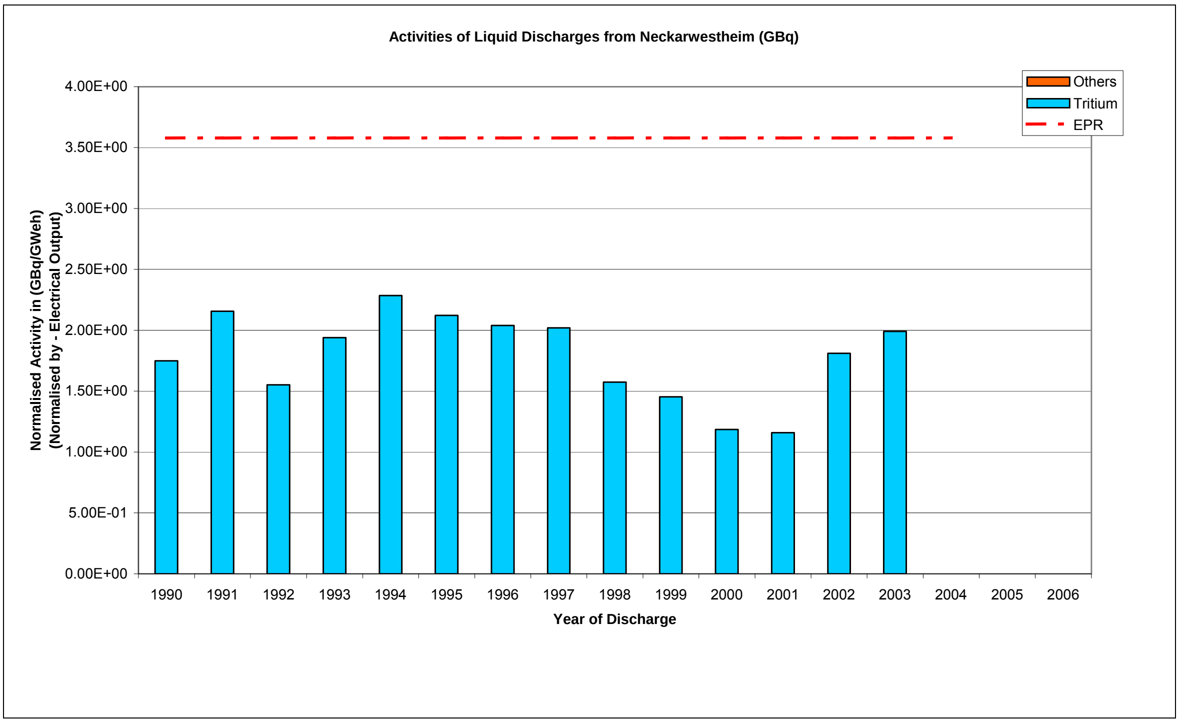

Figure 6.3 Activities of liquid discharges from Neckarwestheim per GWeh.

Figures 6.2 show the raw (non-normalised) discharges from Neckarwestheim, which shows a sinusoidal trend that may coincide with the reactor plant outages. However, following normalisation (Figure 6.3), the sinusoidal trend is still apparent. This provides clear evidence that the fluctuations in discharges are independent of the output power of the reactor power station.

## 6.2 Proportional relationship

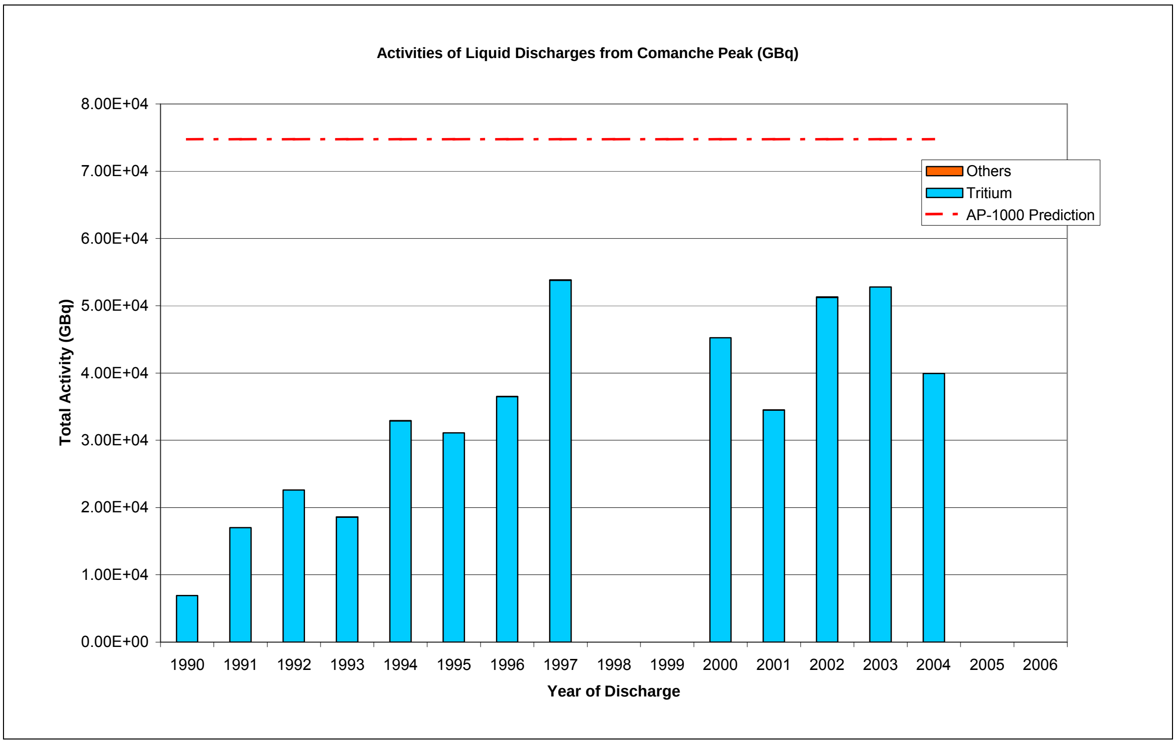

Figure 6.4 Total activity of liquid discharges from Comanche Peak in GBq/a.

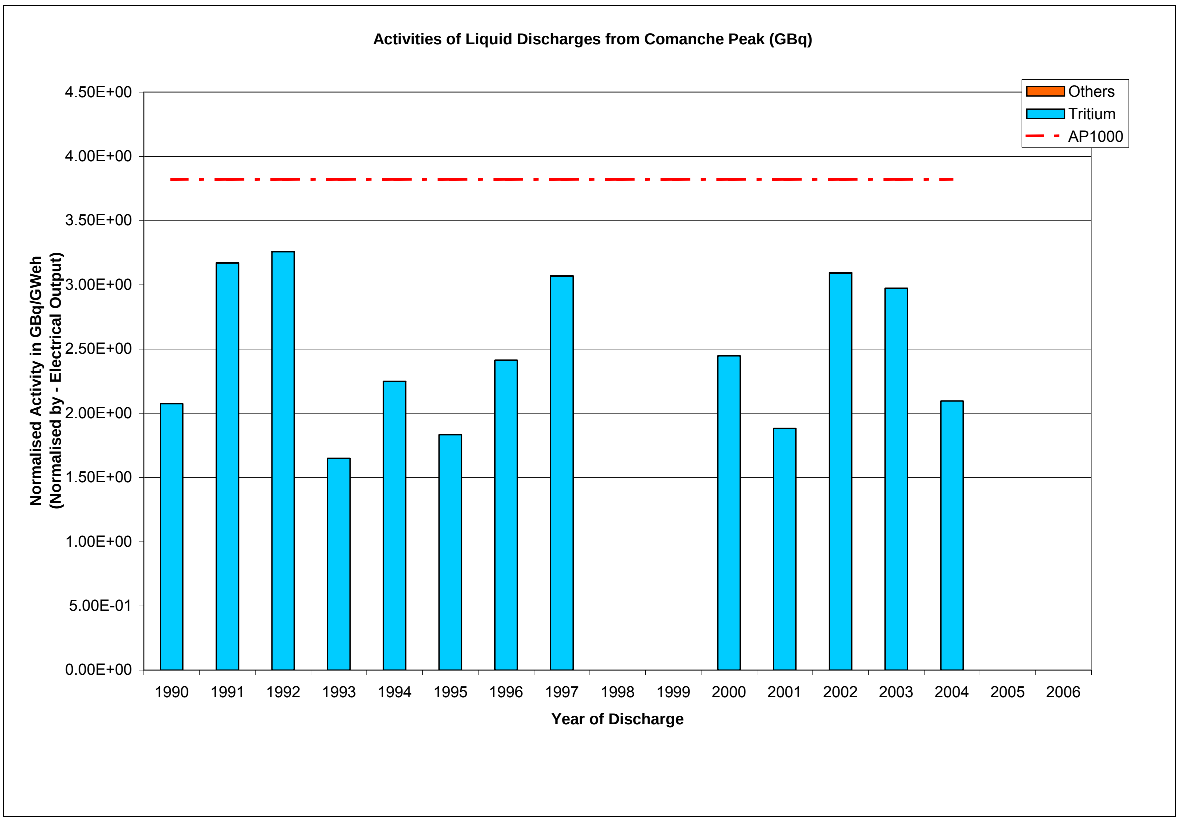

Figure 6.5 Activities of liquid discharges from Comanche Peak per GWeh.

Figure 6.4 and Figure 6.5 show the raw (non-normalised) and normalised data for liquid discharges from the Comanche Peak reactors (AP1000 predecessors). It can be observed from the raw discharges shown in Figure 6.4 that during the period from 1990 to 1997 the liquid discharges increased. Following normalisation, this effect is not as pronounced and the discharge rates (per unit of electrical power output) become more consistent across the period. The normalisation indicates, to a certain extent, that there is a proportional relationship between the discharge and the power output.

However, closer examination suggests that the discharges may not be proportional to the power station’s electrical output. For example, the discharge during 1993 was approximately 1.50 GBq/GWeh, whilst during 1991, 1992 and 1997 it was almost twice that figure (>3.00 GBq/GWeh). It is therefore concluded that there is no linear relationship between discharge and output power.

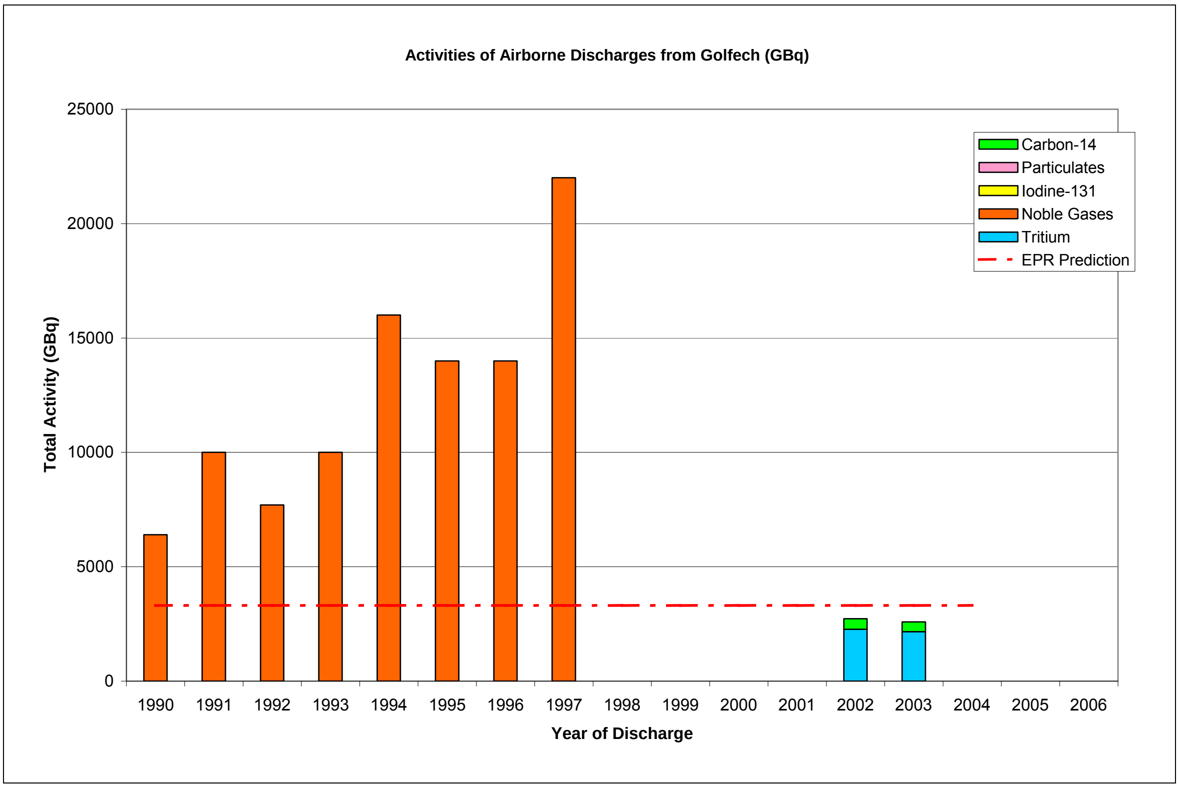

**Figure 6.6 Total activity of airborne discharges from Golfech in GBq/a.**

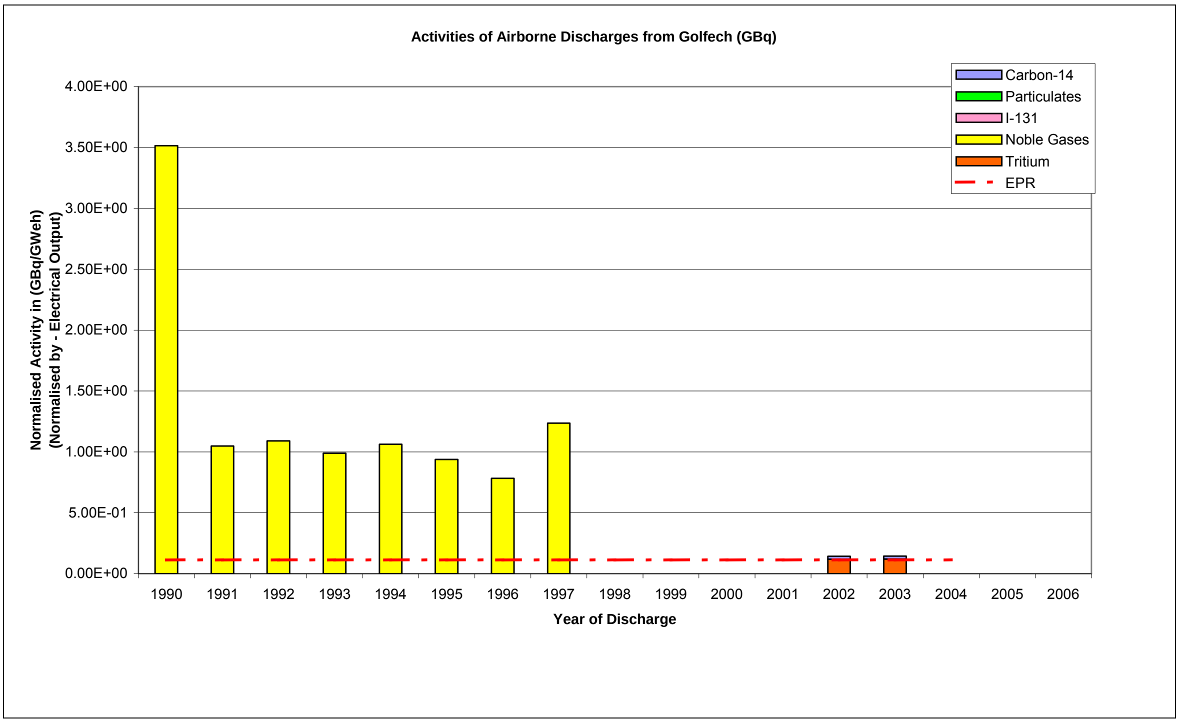

**Figure 6.7 Activities of airborne discharges from Golfech per GWeh.**

Golfech is a prime example of discharge peaks showing proportionality between the levels of discharge and output power. The raw non-normalised discharges (Figure 6.6) show a slightly erratic behaviour. Following normalisation (Figure 6.7), the majority of peaks even out to produce a more consistent trend. The raw discharge data shows a peak in discharge during 1997. This peak coincides with an increase in output power for that year. Hence, the normalised discharge rate for 1997 is less prominent. (The normalisation process is described in more detail in Section 2.3).

## 6.3 Abnormal events

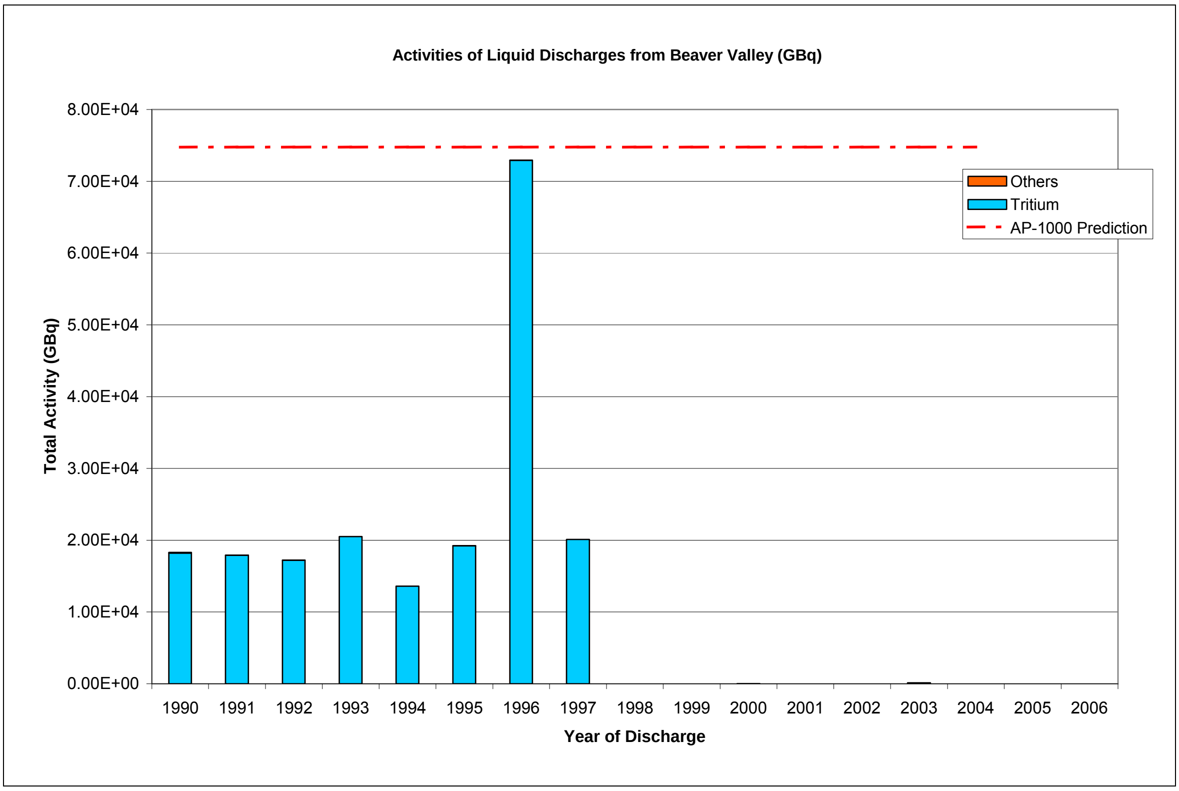

**Figure 6.8 Total activity of liquid discharges from Beaver Valley in GBq/a.**

Figure 6.8 shows the discharges (raw values) from Beaver Valley, an AP1000 predecessor. The peak observed in 1996 is believed to have been at least partly due to an abnormal event. This judgement is made because:

- the discharge during 1996 is significantly higher when compared against the more consistent levels of discharge during other years;
- documentation exists indicating that an abnormal event –the mis-application of leak sealant (NRC Document EA-96-462) – occurred at the power station during 1996 which may have caused the apparent increase in discharge.

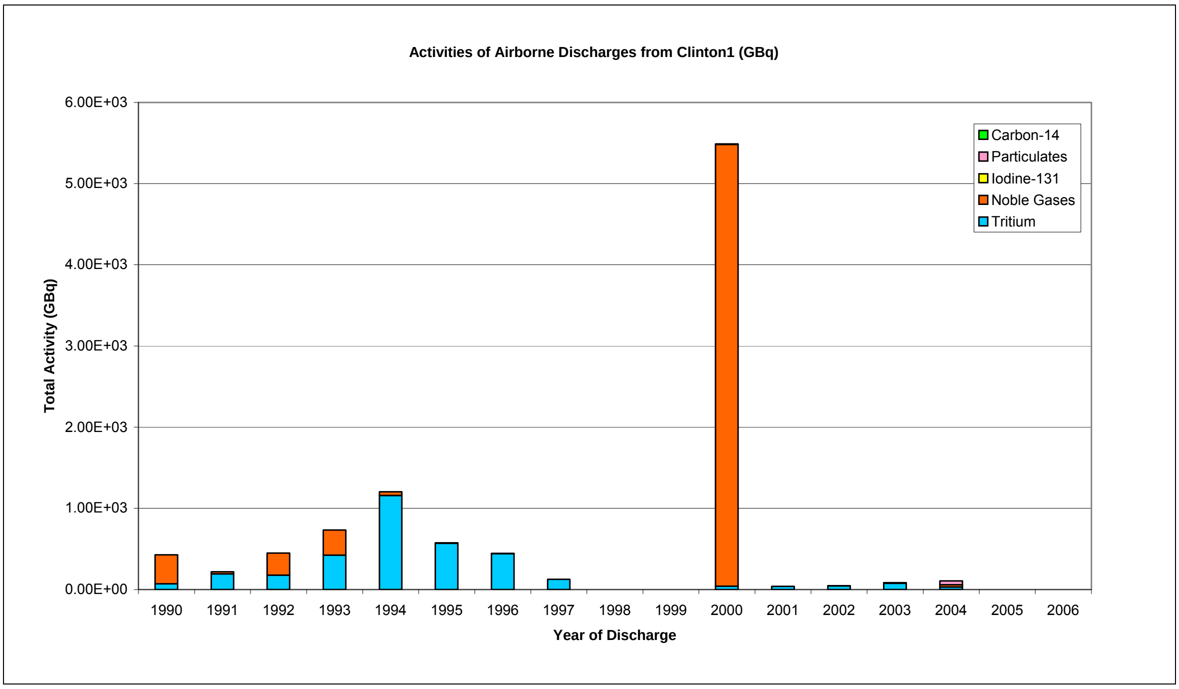

**Figure 6.9 Total activity of airborne discharges from Clinton-1 in GBq/a.**

Clinton-1 shows a very distinctive peak in 2000 (see Figure 6.9); this peak is also thought to be due to an abnormal event, at least in part. In this particular case, two hydramotor pump assemblies had to be replaced, one belonging to the gas treatment system fuel building. It is assumed that the discharge for this year was unusually high due to work involved in replacing and testing the pumps. However, more comprehensive studies may identify other possible events that could explain this peak in discharge.

## 6.4 Average and standard deviation

### 6.4.1 Average and standard deviation by discharge group

Table 6.1 presents the average discharge, the standard deviation, the maximum discharge and the predicted discharge values for each radionuclide discharge group, for each predecessor reactor class as detailed in Chapter 5.

**Table 6.1 Average and standard deviation of predecessor designs.**

| Design | Waste stream | Average GBq/GWeh | Standard deviation GBq/GWeh | Maximum GBq/GWeh | Predicted GBq/GWeh |
|---|---|---|---|---|---|
| **AP1000** | Liquid tritium | 3.03E+00 | 1.58E+00 | 4.61E+00 | 3.82E+00 |
| | Other liquids | 2.18E-03 | 2.44E-03 | 4.62E-03 | 9.69E-04 |
| | *Total liquid* | *3.03E+00* | 1.58E+00 | *4.61E+00* | *3.82E00* |
| | Airborne tritium | 2.12E-01 | 3.26E-01 | 5.38E-01 | 1.32E+00 |
| | Airborne noble gases | 2.80E-01 | 4.16E-01 | 6.96E-01 | 4.17E+01 |
| | Airborne iodine-131 | 1.35E-05 | 4.34E-05 | 5.69E-05 | 4.54E-04 |
| | Airborne particulates | 2.72E-06 | 5.45E-06 | 8.17E-06 | 1.79E-04 |
| | Airborne carbon-14 | 1.80E-02 | 8.60E-03 | 2.66E-02 | 2.76E-02 |
| | *Total airborne* | *5.10E-01* | 7.51E-01 | *1.26E+00* | *4.30E+01* |
| **EPR** | Liquid tritium | 1.68E+00 | 7.50E-01 | 2.43E+00 | 3.58E+00 |
| | Other liquids | 6.85E-05 | 1.36E-04 | 2.04E-04 | 1.62E-03 |
| | *Total liquid* | *1.68E+00* | 7.50E-01 | *2.43E+00* | *3.58E+00* |
| | Airborne tritium | 8.50E-02 | 5.90E-02 | 1.44E-01 | 3.42E-02 |
| | Airborne noble gases | 4.81E-01 | 7.19E-01 | 1.20E+00 | 5.50E-02 |
| | Airborne iodine-131 | 1.05E-06 | 1.95E-06 | 3.00E-06 | 1.57E-06 |
| | Airborne particulates | 1.48E-07 | 2.32E-07 | 3.80E-07 | 2.75E-07 |
| | Airborne carbon-14 | 3.07E-02 | 1.39E-02 | 4.46E-02 | 2.41E-02 |
| | *Total airborne* | *5.97E-01* | 7.93E-01 | *1.39E+00* | *1.13E-01* |
| **ESBWR** | Liquid tritium | 4.04E-02 | 3.25E-02 | 7.29E-02 | 3.79E-02 |
| | Other liquids | 1.37E-04 | 1.88E-04 | 3.25E-04 | 2.65E-04 |
| | *Total liquid* | *4.05E-02*[a] | 3.27E-02[a] | *7.32E-02* | *3.82E-02* |
| | Airborne tritium | 6.53E-02 | 8.37E-02 | 1.49E-01 | 2.05E-01 |
| | Airborne noble gases | 3.92E-01 | 6.18E-01 | 1.01E+00 | 1.12E+01 |
| | Airborne iodine-131 | 2.82E-06 | 5.24E-06 | 8.06E-06 | 1.10E-03 |
| | Airborne particulates | 3.42E-05 | 1.52E-04 | 1.86E-04 | 3.59E-04 |
| | Airborne carbon-14 | Not available | Not available | Not available | Not available |
| | *Total airborne* | *4.57E-01*[a] | 7.03E-01[a] | *1.16E+00* | *1.14E+01* |

Table 6.1 continued overleaf

**Table 6.1 continued**

| Design | Waste stream | Average GBq/GWeh | Standard deviation GBq/GWeh | Maximum GBq/GWeh | Predicted GBq/GWeh |
|---|---|---|---|---|---|
| ACR-1000 | Liquid tritium | 3.74E+01 | 3.73E+01 | 7.47E+01 | 1.26E+01 |
| | Other liquids | 2.03E-03 | 2.37E-03 | 4.40E-03 | 1.47E-03 |
| | *Total liquid* | *3.74E+01*[b] | 3.73E+01 [b] | *7.47E+01* | *1.26E+01* |
| | Airborne tritium | 3.68E+01 | 4.12E+01 | 7.80E+01 | 5.26E+00 |
| | Airborne noble gases | 1.44E+01 | 4.24E+01 | 5.68E+01 | 1.68E+00 |
| | Airborne iodine-131 | 5.66E-06 | 1.10E-05 | 1.67E-05 | 8.42E-07 |
| | Airborne particulates | 1.24E-05 | 5.35E-05 | 6.59E-05 | Not available |
| | Airborne carbon-14 | 1.81E-01 | 2.36E-01 | 4.17E-01 | 2.95E-02 |
| | *Total airborne* | *5.14E+01*[b] | 8.36E+01[b] | *1.35E+02* | *6.97E+00* |

Notes: [a] Lowest
[b] Highest

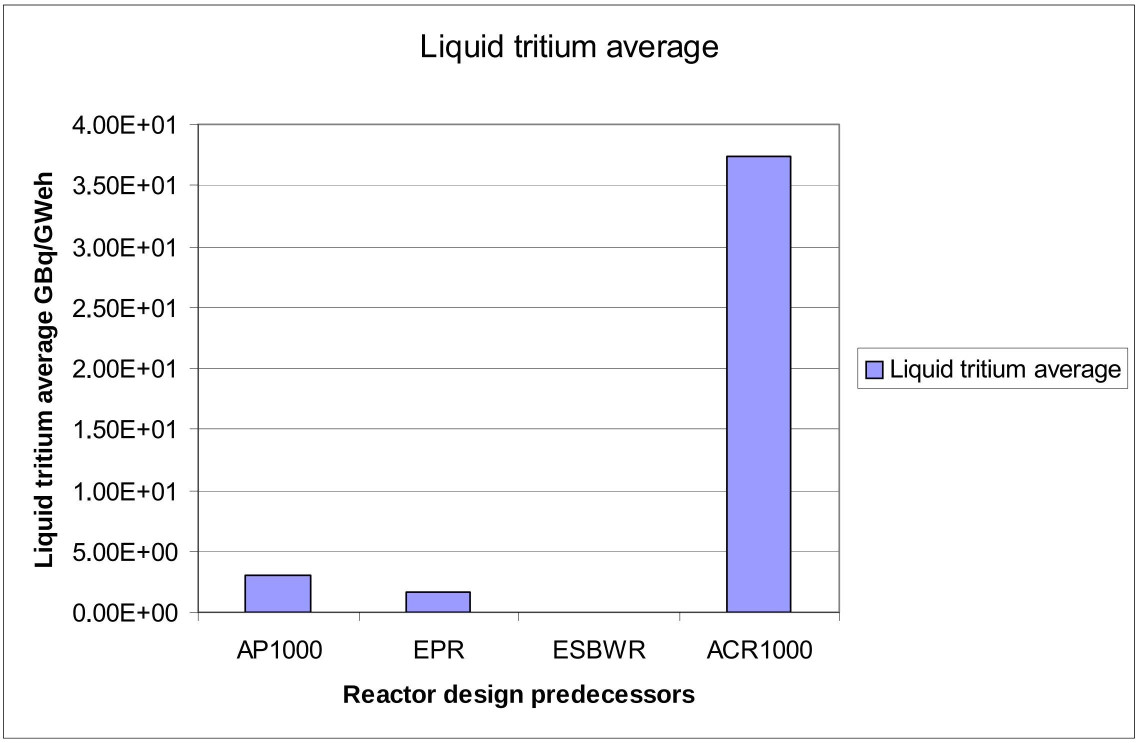

**Figure 6.10 Liquid tritium average for candidate predecessors.**

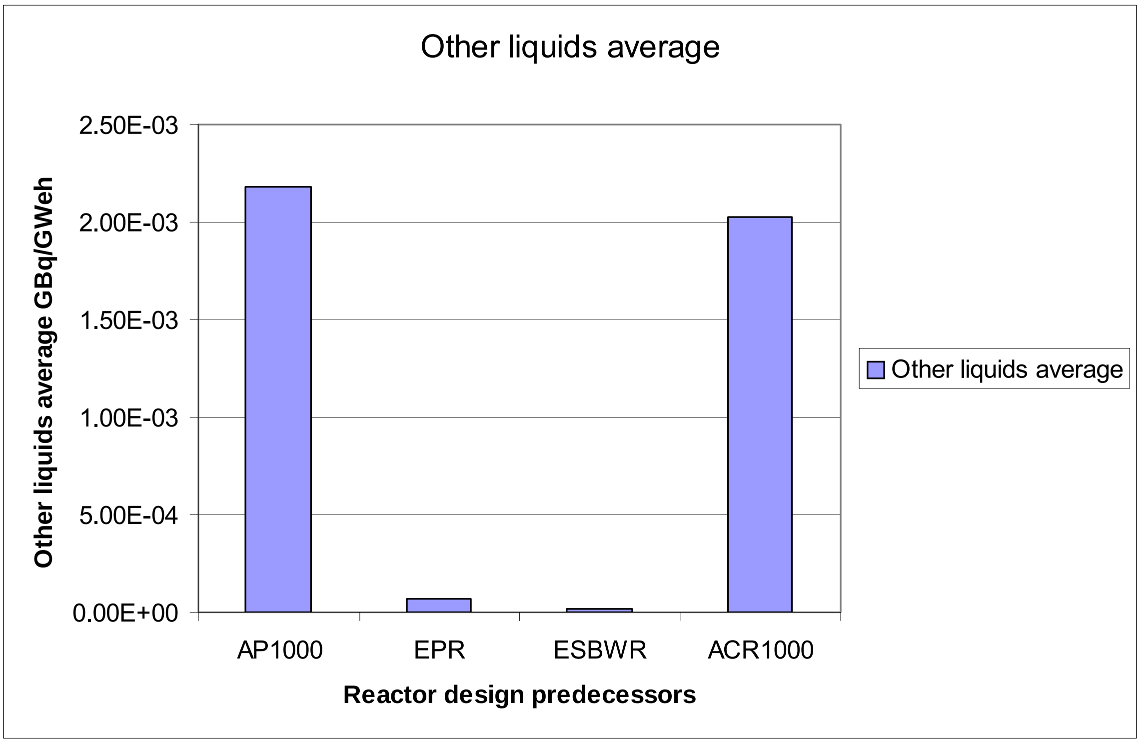

Figure 6.11 Other liquids average for candidate predecessors.

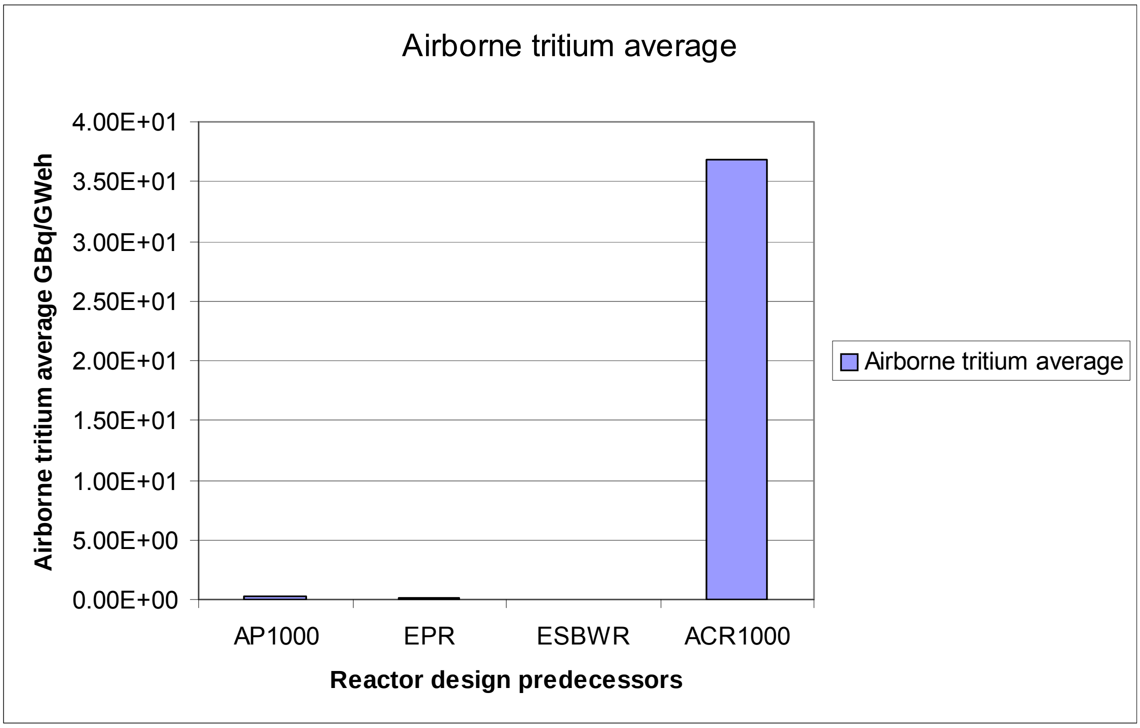

Figure 6.12 Airborne tritium average for candidate predecessors.

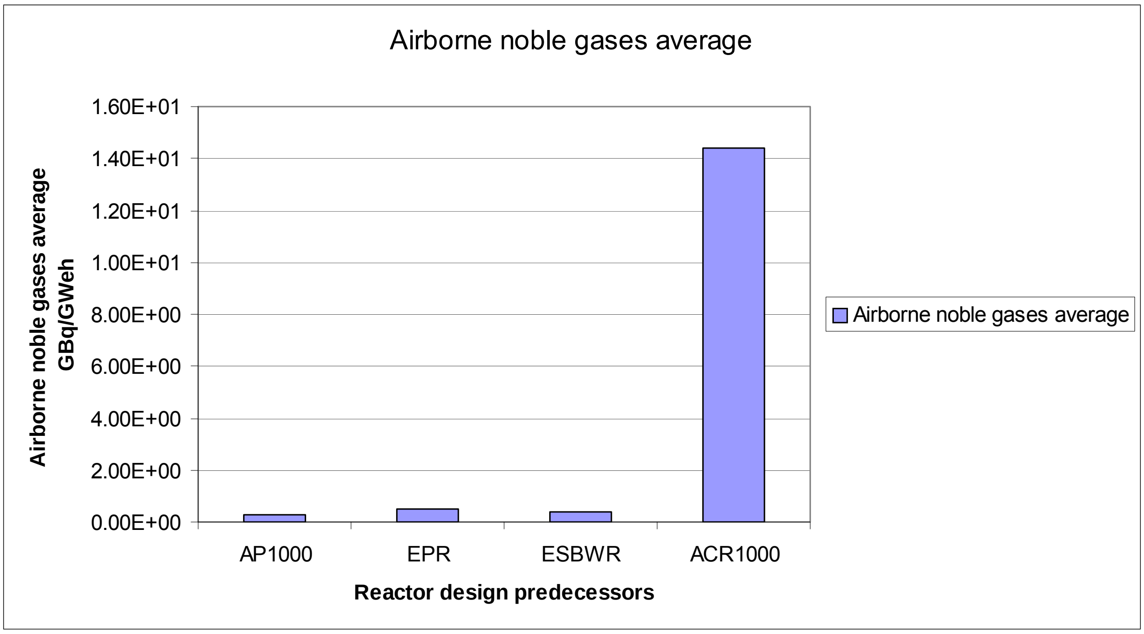

**Figure 6.13 Airborne noble gases average for candidate predecessors.**

Please note that discharges of noble gases for ACR-1000 predecessors were reported as GBq-MeV units.

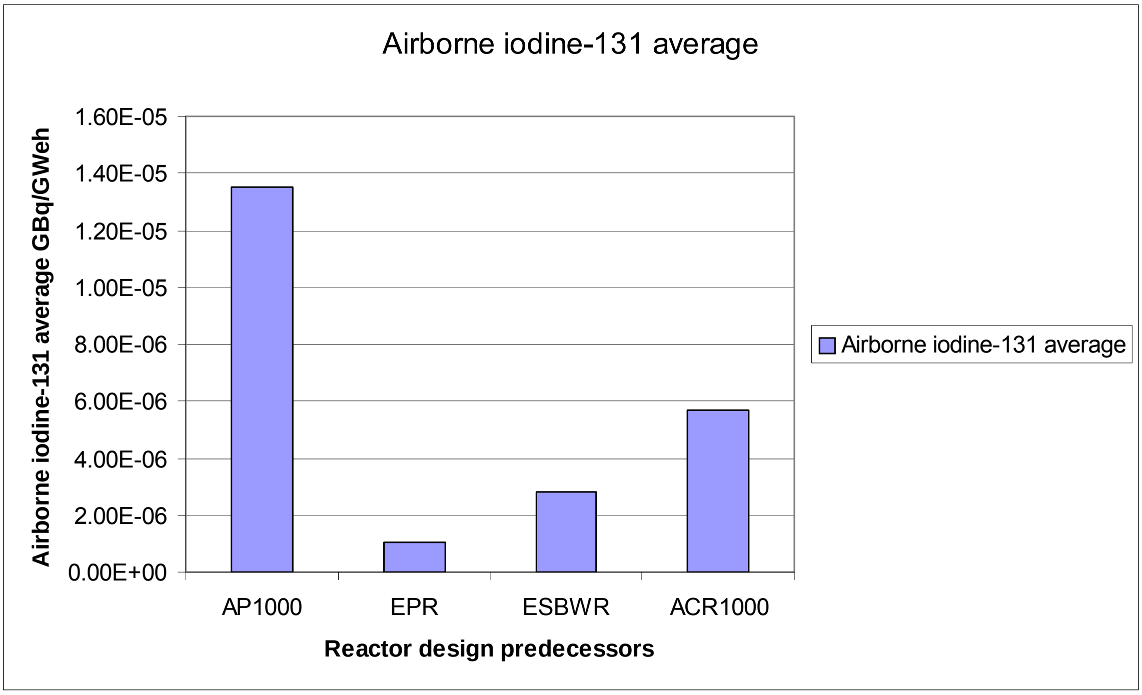

**Figure 6.14 Airborne iodine-131 average for candidate predecessors.**

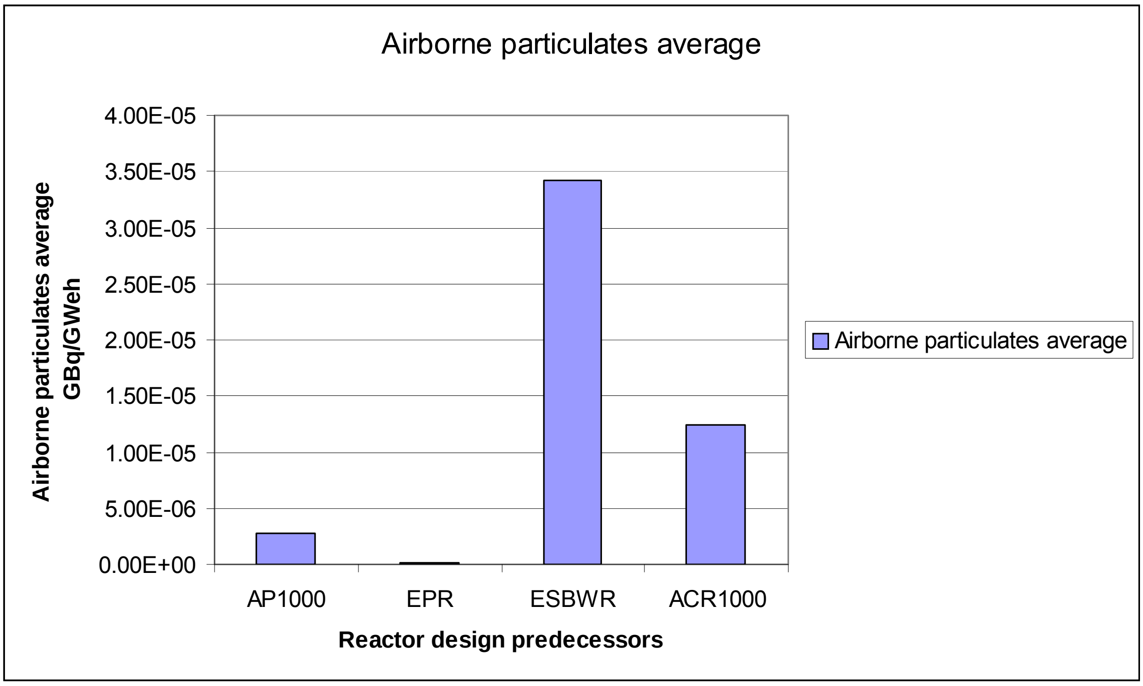

Figure 6.15 Airborne particulates average for candidate predecessors.

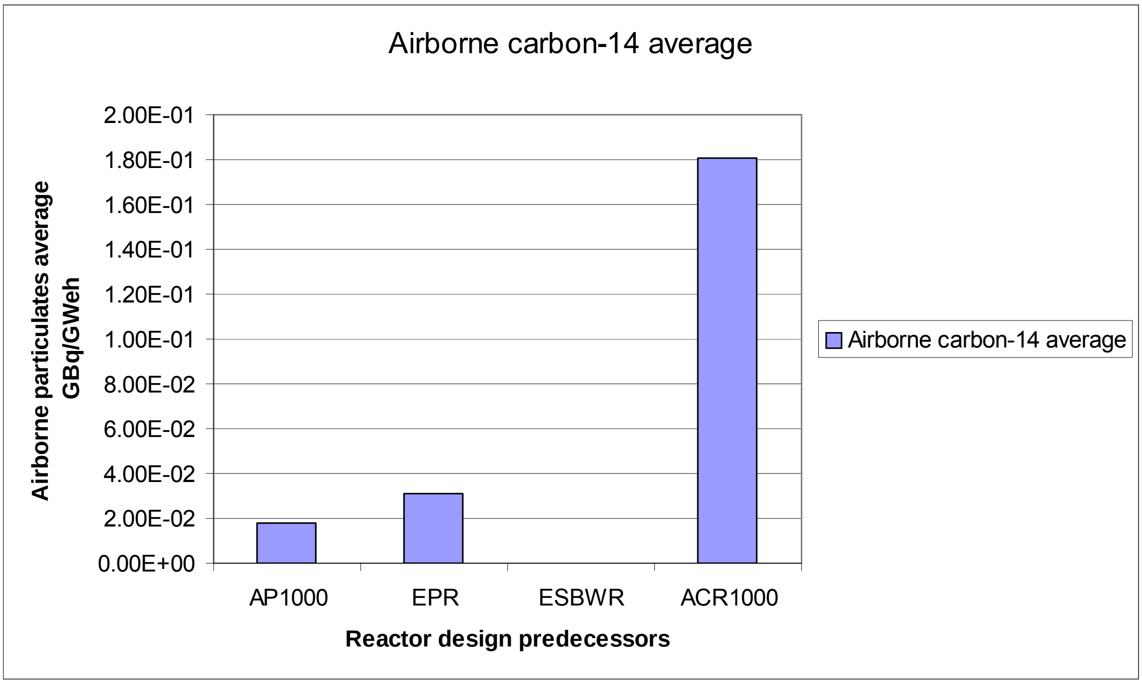

Figure 6.16 Airborne carbon-14 average for candidate predecessors.

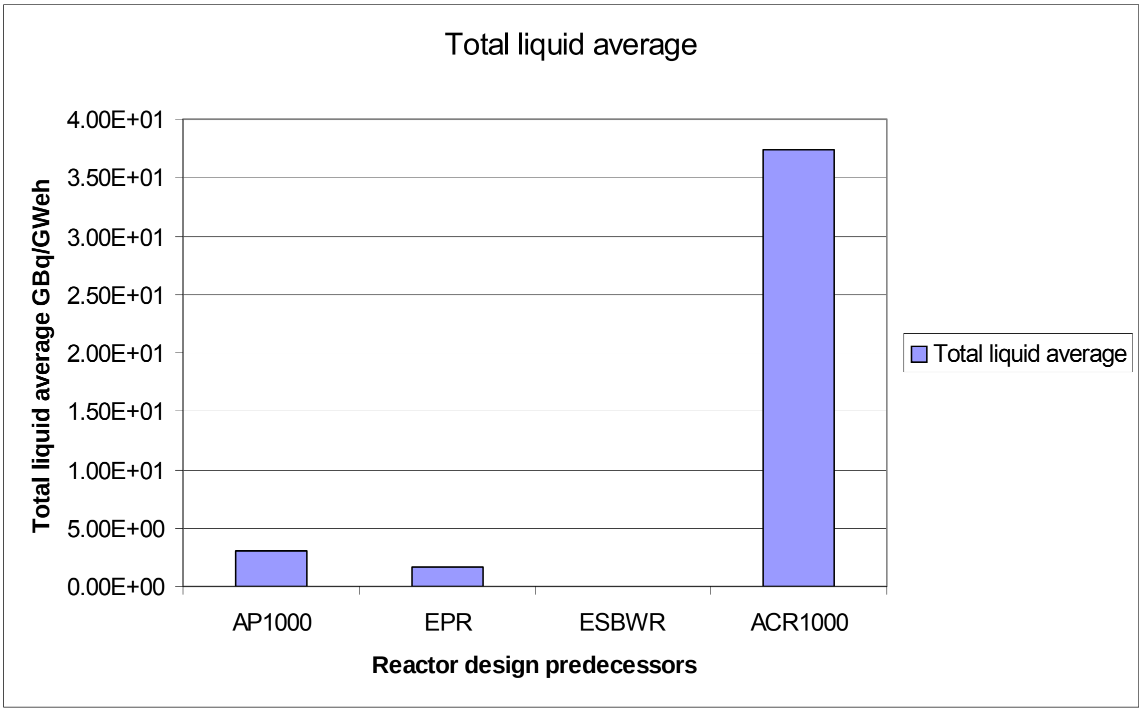

**Figure 6.17 Total liquid average for candidate predecessors.**

For comparison, the ACR-1000 discharges have been excluded from Figure 6.18.

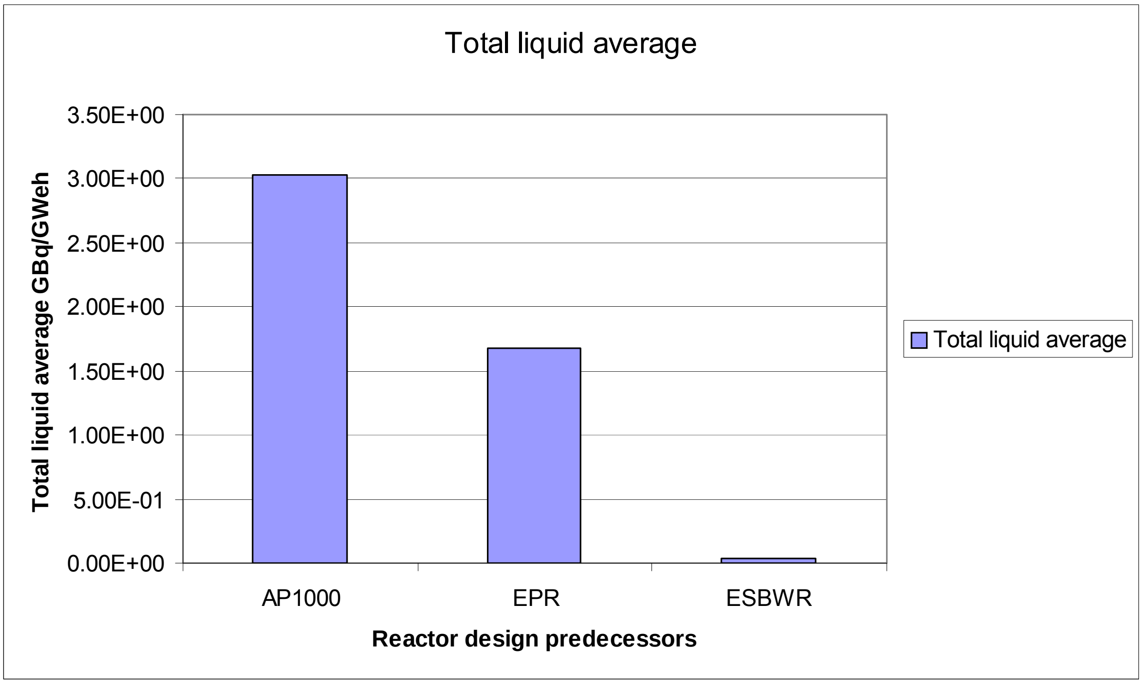

**Figure 6.18 Total liquid average for candidate predecessors – excluding ACR-1000.**

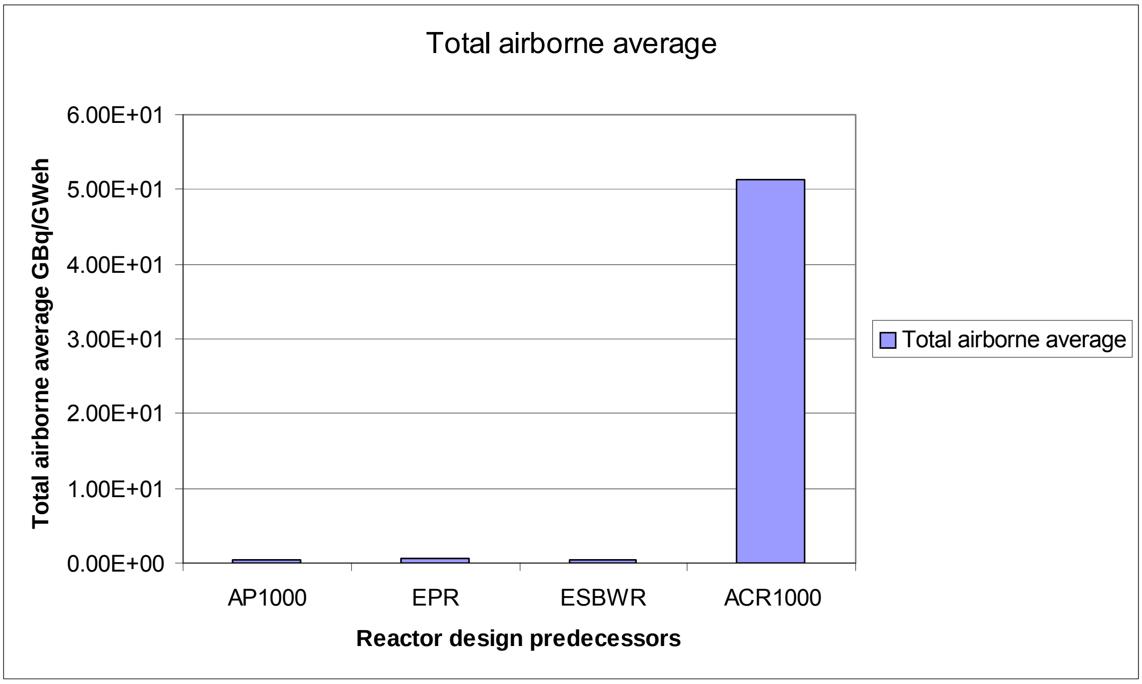

Figure 6.19 Total airborne average for candidate predecessors.

For comparison with Figure 6.18, the ACR-1000 discharges have been excluded from Figure 6.20.

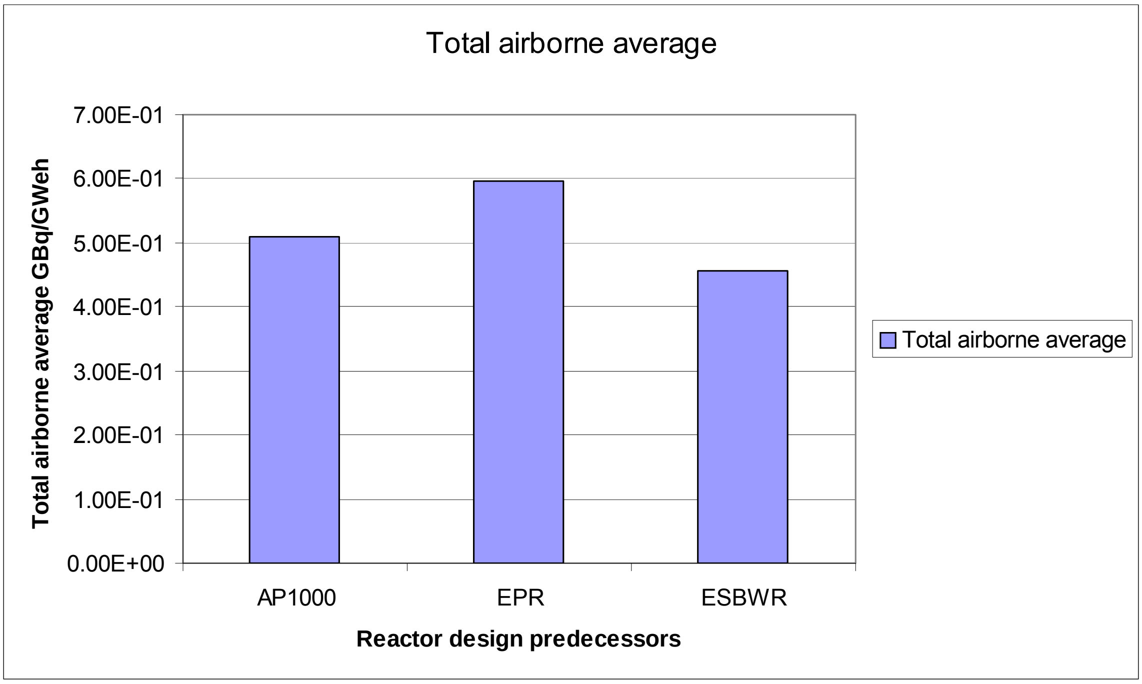

Figure 6.20 Total airborne average for candidate predecessors – excluding ACR-1000.

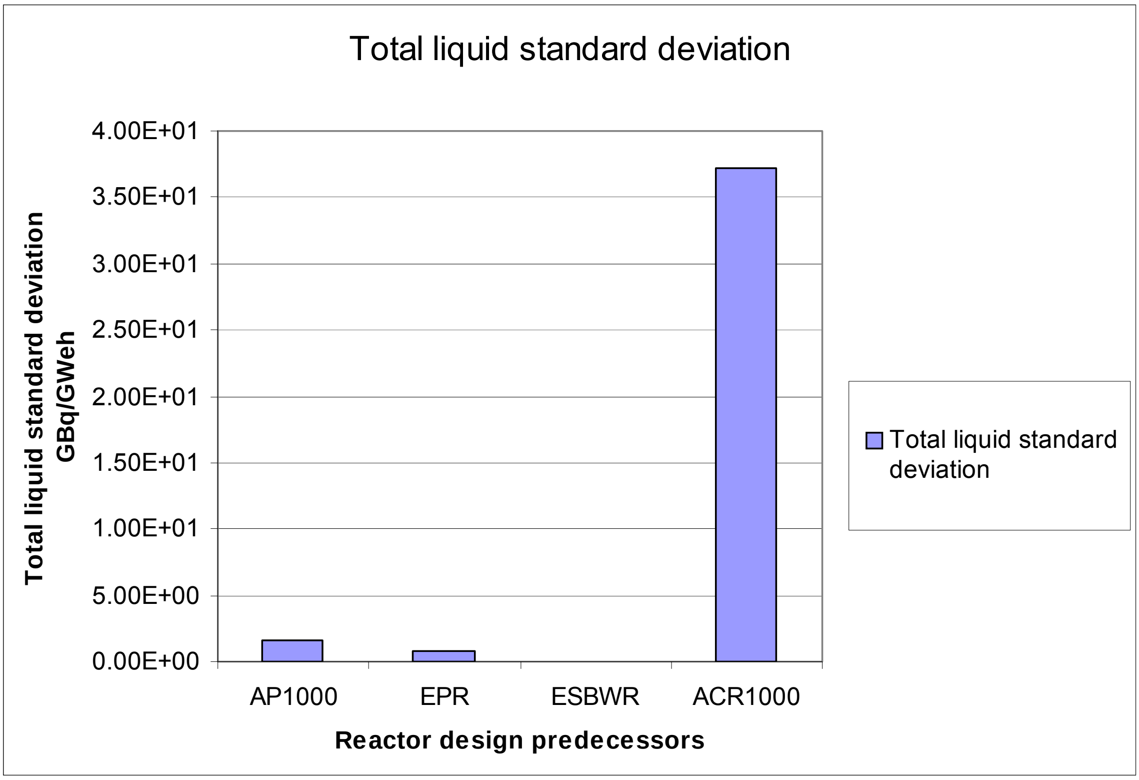

**Figure 6.21 Total liquid standard deviation for candidate predecessors.**

For comparison, the ACR-1000 discharges have been excluded from Figure 6.22.

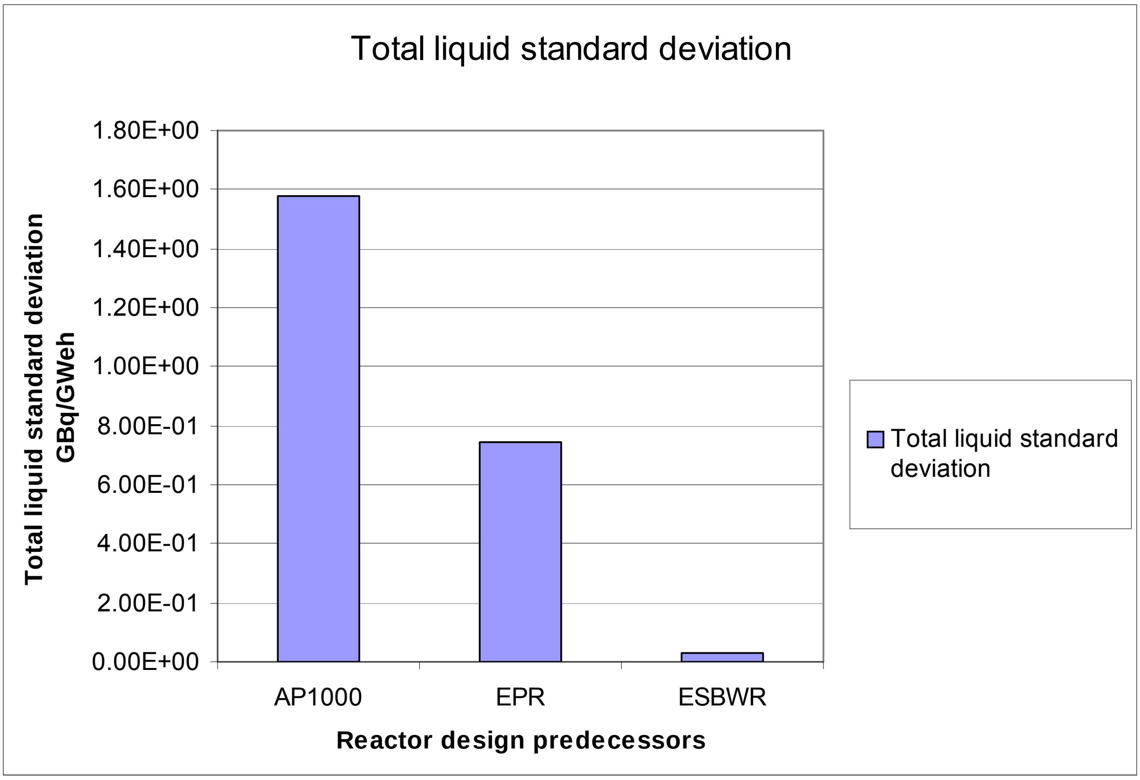

**Figure 6.22 Total liquid standard deviation for candidate predecessors – excluding ACR-1000.**

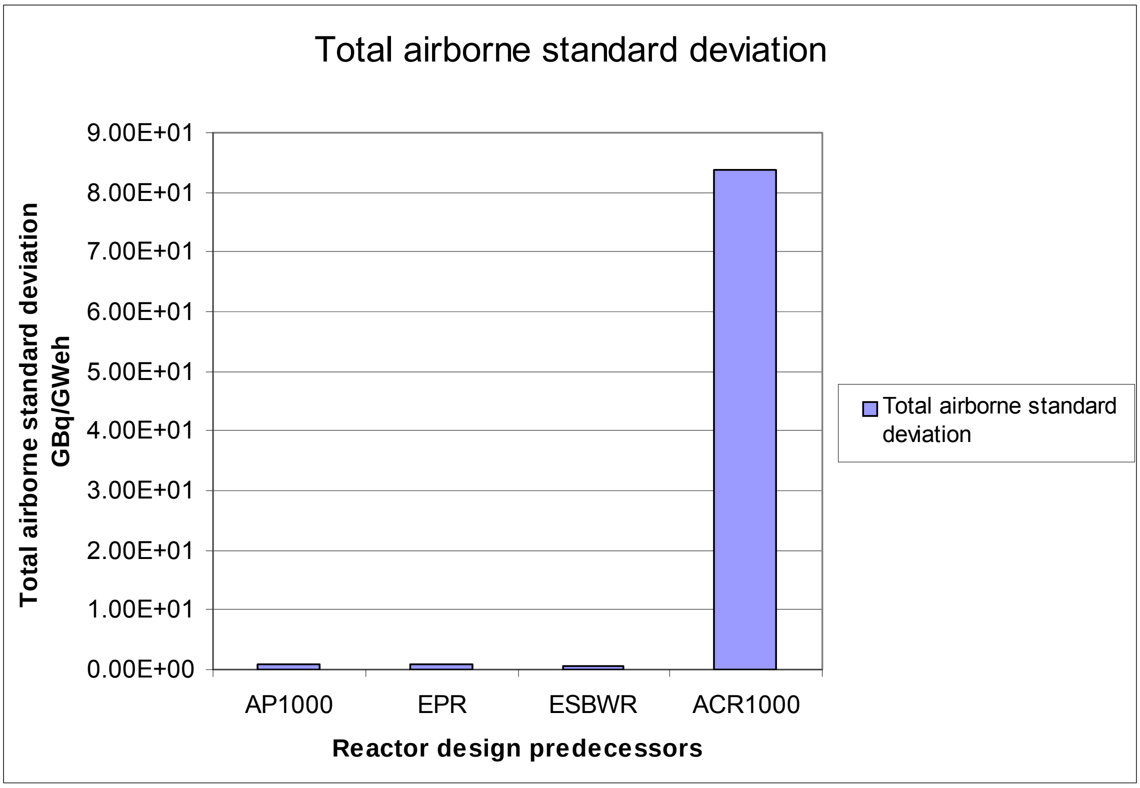

**Figure 6.23 Total airborne standard deviation for candidate predecessors.**

For comparison, the ACR-1000 discharges have been excluded from Figure 6.24.

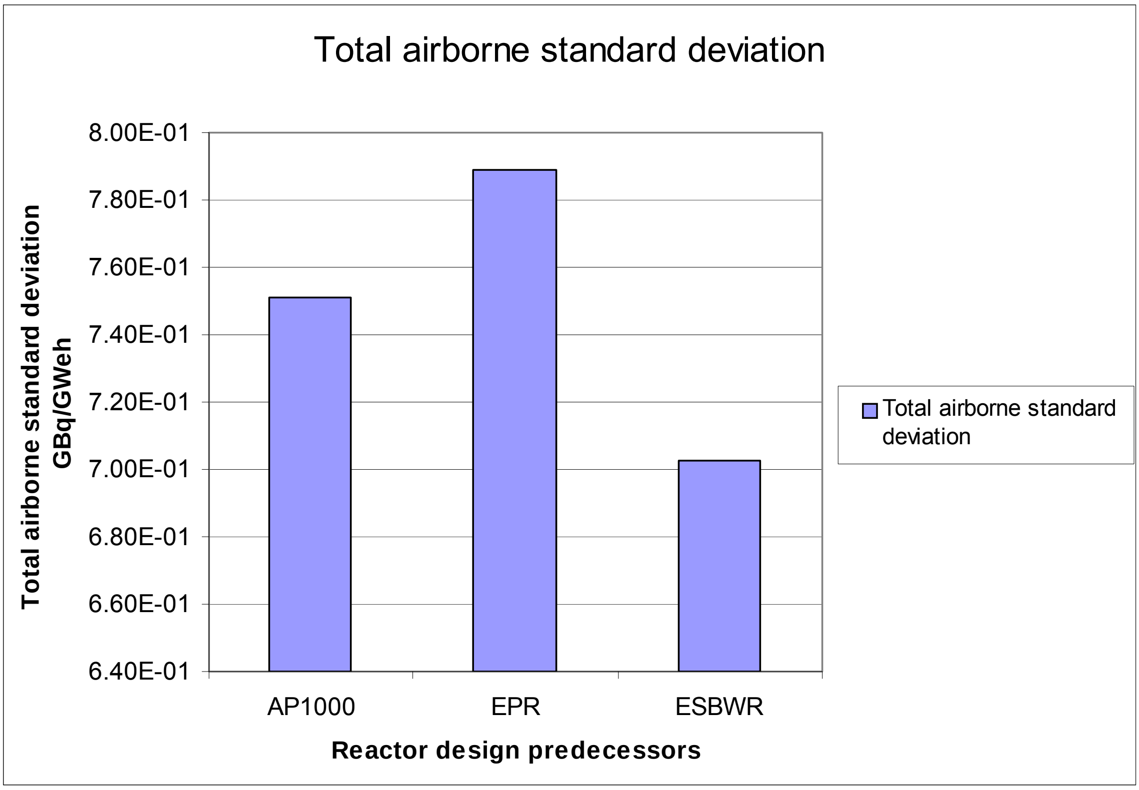

**Figure 6.24 Total airborne standard deviation for candidate predecessors – excluding ACR-1000.**

### 6.4.2 What can be inferred from the data?

Any conclusions identified below are based purely on the use of the ‘methodology’ detailed in Chapter 2. In calculating the values presented in the preceding sections of this report, assumptions and information gaps have been detailed and applied throughout the report. The methodology aims to rationalise the reported discharge parameters to allow sensible comparison to be made.

A large standard deviation indicates that the data points fluctuate significantly about the mean (average). A small standard deviation indicates that the data points are clustered more closely around the mean (average).

The output from this study is intended for the Environment Agency to inform its assessment of the submitted generic reactor designs and Best Available Techniques (BAT) in this field. Further investigation and justification is required to identify whether the discharge levels highlighted for each reactor class should be judged as BAT, within the acceptable safety operating region of the technology or above the limit of acceptability.

### 6.4.3 Westinghouse AP1000

The AP1000 predecessors produce the highest average discharge of non tritium liquids (i.e. other liquids) (Figure 6.11).

The AP1000 predecessors show the second highest total average liquid discharge value (Figure 6.17 and Figure 6.18).

The AP1000 predecessors produce the highest average discharge of iodine-131 (Figure 6.14).

The AP1000 class also produces the lowest average discharge of airborne noble gas and carbon-14 (although carbon-14 data was not available for the ESBWR class) (Figure 6.13 and Figure 6.16, respectively).

The lower average discharges of noble gases and carbon-14 result in the AP1000 predecessors showing the second lowest total average airborne discharge value (Figure 6.19 and Figure 6.20).

### 6.4.4 EDF/Areva EPR

The EPR predecessors produce the lowest average discharge of non-tritium (other) liquid discharges (Figure 6.11).

They also show the second lowest value for total average liquid discharges (Figure 6.17 and Figure 6.18).

The EPR predecessors show the lowest average discharge of airborne iodine-131 and particulates (Figure 6.14 and Figure 6.15).

However, the EPR predecessors also show the second highest value for total average airborne discharges (Figure 6.19 and Figure 6.20).

### 6.4.5 GE-Hitachi ESBWR

The ESBWR predecessors produce the lowest average discharge of liquid tritium (Figure 6.10).

This low tritium discharges result in the ESBWR predecessors producing the lowest value for total average liquid discharges (Figure 6.17 and Figure 6.18).

The ESBWR predecessors produce the highest average discharge of airborne particulates (Figure 6.15), but the lowest average discharge of airborne tritium (Figure 6.12).

ESBWR predecessors produce the lowest value for total average airborne discharges (Figure 6.19 and Figure 6.20).

The ESBWR predecessors provide the lowest standard deviations (Figure 6.21 to Figure 6.24). This implies that the discharges are clustered closely around the average values and are more consistent across the reactor power stations studied when compared with the discharges evident from the AP1000, EPR and ACR-1000 predecessors.

### 6.4.6 AECL ACR-1000

The ACR-1000 predecessors produce the highest average discharge of liquid tritium (Figure 6.10), although the predicted liquid tritium discharges of the ACR-1000 are also the highest of the four proposed designs.

The average discharge for other liquids is also relatively high, resulting in the ACR-1000 predecessors producing the highest total average liquid discharge (Figure 6.17).

The ACR-1000 predecessors produce the highest average discharge of airborne tritium, noble gas and carbon-14 (Figure 6.12, Figure 6.13 and Figure 6.16). As a result, the ACR-1000 predecessors also have the highest total average airborne discharges (Figure 6.19).

The ACR-1000 predecessors show the largest total standard deviation values for both liquid and airborne discharges (Figure 6.21 and Figure 6.23). This implies that the discharges evident from the individual ACR-1000 predecessor reactor power stations fluctuate more significantly about the mean value than the individual discharges evident from the AP1000, EPR and ESBWR predecessors. This greater variation may be explained by a number of factors, such as the occurrence of abnormal events, reactor outage and shutdown etc. However, further investigation will be required to provide explanations for this effect and to draw effective conclusions.

### 6.4.7 Average and standard deviation by discharge type

The total average and total standard deviation for airborne and liquid discharges were calculated by summing the average discharges and standard deviations for the individual discharge groups. The results are shown in Figure 6.25 and Figure 6.26 below. The standard deviation is represented by the error bars.

It was observed that the average as well as the standard deviation for the ACR-1000 predecessors was significantly greater than the values calculated for the predecessors of the other three designs. The averages and standard deviations for the AP1000, EPR and ESBWR predecessors are show independently in Figure 6.27 and Figure 6.28.

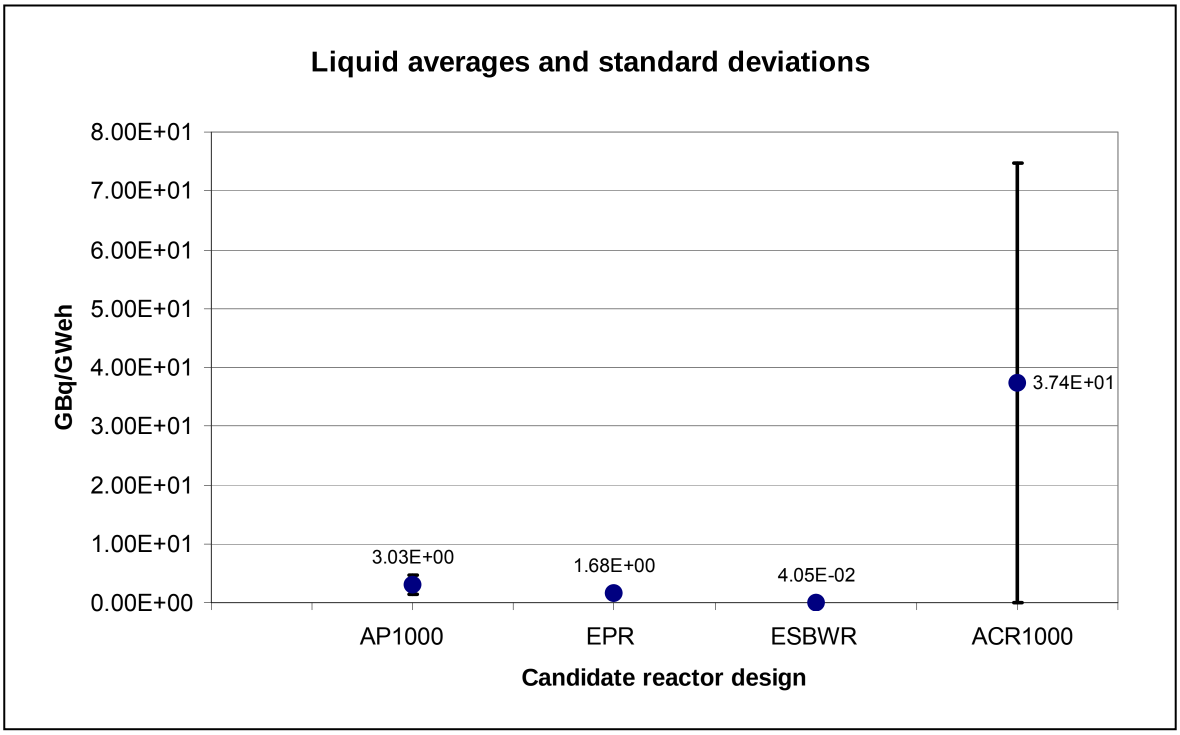

Figure 6.25 Liquid averages and standard deviations.

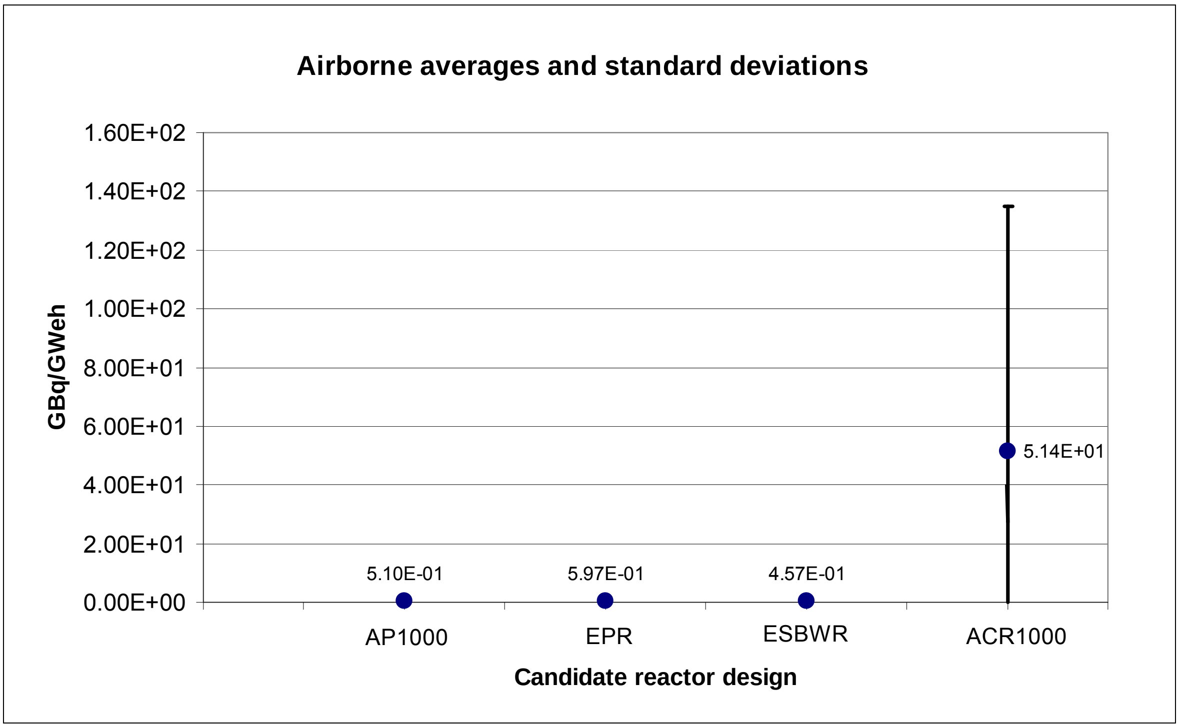

Figure 6.26 Airborne averages and standard deviations.

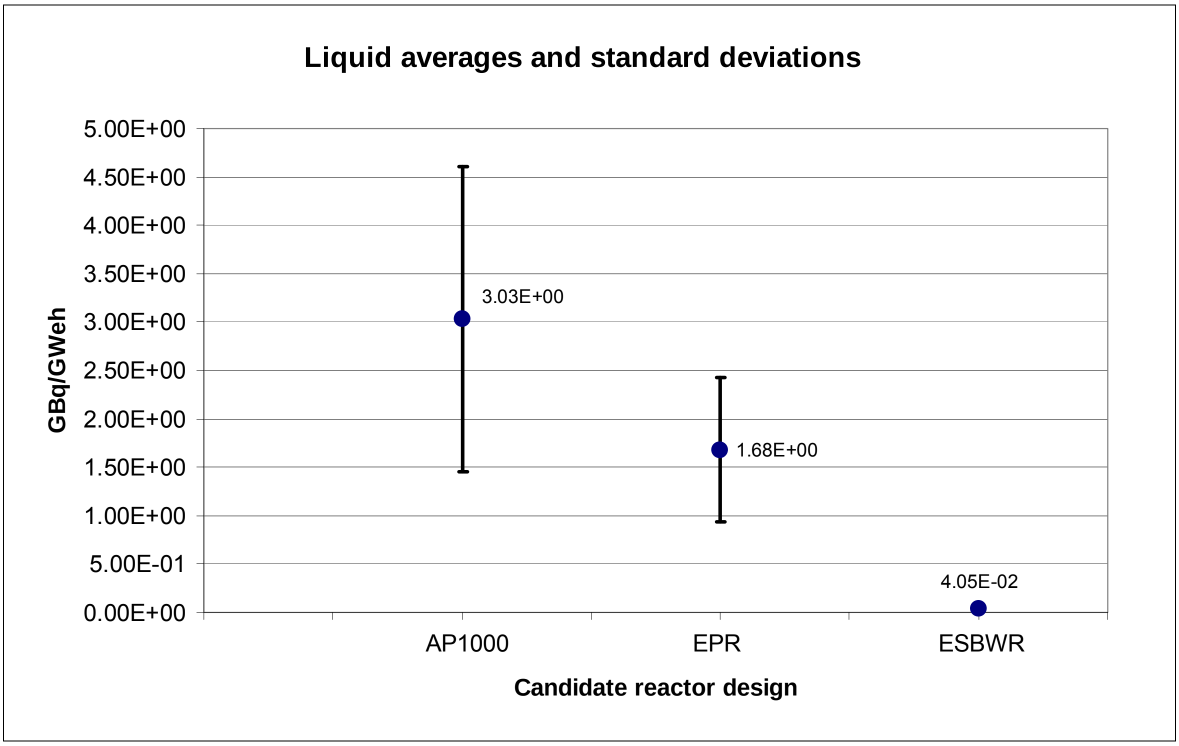

Figure 6.27 Liquid averages and standard deviations excluding ACR-1000 predecessor data.

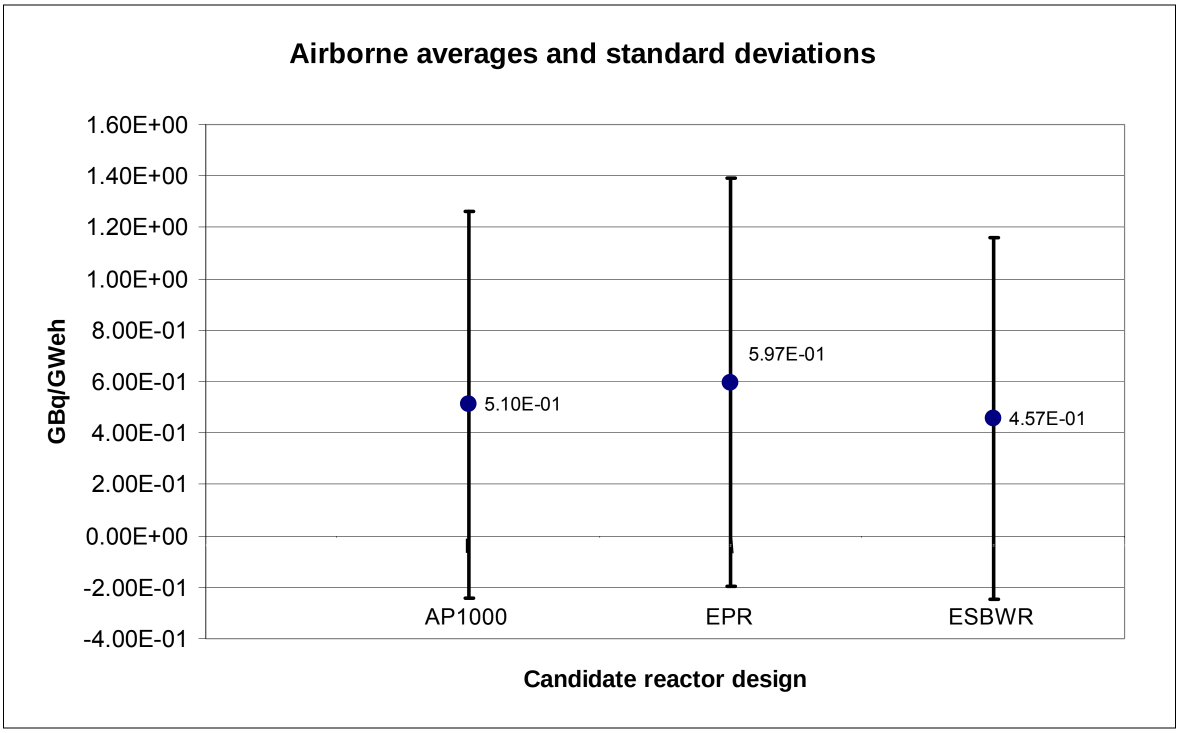

Figure 6.28 Airborne averages and standard deviations excluding ACR-1000 predecessor data.

It can be observed from Figure 6.27 that the ESBWR predecessors show the lowest average and standard deviation for liquid discharges.

The predecessors to the AP1000, EPR and ESBWR designs all share approximately the same level of airborne discharges (Figure 6.28).

### 6.4.8 Best performing reactors by discharge groups

The average discharge for each candidate reactor was calculated in order to establish the best performing reactor for each of the discharge groups. The results are shown in Table 6.2. Any reactors for which data was only available for a limited number of years (five years or less), were excluded from these calculations.

**Table 6.2 Best performing predecessor reactors by discharge groups.**

| Discharge group | Best performer(s) | Discharge in GBq/GWeh |
|---|---|---|
| Liquid tritium | Kashiwazaki | 1.06E-02 |
| Liquid others | Emsland | 1.32E-07 |
| | | |
| Airborne tritium | Byron | 1.56E-02 |
| Airborne noble gases | Takahama | 1.47E-02 |
| Airborne iodine-131 | Emsland | 8.59E-08 |
| Airborne particulates | Hamaoka<br>Kashiwazaki<br>Shika | 0.00E+00 |
| Airborne carbon-14 | Sizewell B | 1.80E-02 |

It should be noted that the best performing reactors shown above are not necessarily the best of all reactors currently operating but rather the best amongst those studied in this project (See Section 3.1).

However, one can say with 99 per cent confidence (see Section 2.5.1) that the mean for the total population will have a value that falls within a range that is 2.58σ (i.e. 2.58 × standard deviation) above or below the study sample mean. Therefore, the minimum extreme of the range will be the mean−2.58σ.

### 6.4.9 Summary points

- ACR-1000 predecessors give the highest total liquid and airborne averages and highest standard deviations;
- ESBWR predecessors give the lowest total liquid and airborne averages and the lowest standard deviations;
- EPR and AP1000 predecessors both show small variation in total liquid and airborne averages, when compared with the ACR-1000 and ESBWR predecessors.

### 6.4.10 Future work

An assessment of the radiological impacts of the reactor predecessor discharges would serve to support the results and conclusions drawn in this study. This radiological impact assessment would investigate areas and environmental surroundings near to, and a reasonable distance from, the reactor sites.

This work would include further investigations into the distribution of discharges throughout the year. Discharges are recorded annually and the levels reported are those taken at the point of discharge. The radiological implications of the discharge are subject to variation due to local, climatic and other effects. For example, the discharges may be clustered around specific periods of the year for a particular reason.

It is recognised that sourcing data from each reactor power station has posed many problems. Although attempts were made to contact each candidate reactor operator, very limited success was achieved. It is believed that more reliable conclusions could be drawn with access to a more complete set of data and the "filling in" of the gaps in information outlined in Section 3.4. The AREVA Risk Management Consulting Ltd project team feels that better contact and assistance may be possible by directly approaching the operators and GDA vendors.

Despite these difficulties, conclusions have been drawn from the available discharge data. It is anticipated that a review will be required to ascertain the confidence limits of the analysis and the conclusions.

Due the timescale and time restrictions of this project, AREVA Risk Management Consulting Ltd has been unable to source any information from the next instalment of the UNSCEAR report. This latest instalment of the UNSCEAR report was due for issue during 2007, but was delayed, hence the absence of data for certain periods in this report.

An initial comparison of the historical discharges and the predicted discharges from the proposed new designs is also provided below as a preliminary to future work recommended by AREVA Risk Management Consulting Ltd.

### 6.4.11 Comparison of predicted discharges

The predicted discharges from each of the four proposed designs are shown in Table 6.3, and in Figure 6.29 and Figure 6.30. It is observed that the ESBWR and the EPR designs are the most ambitious for liquid and airborne discharges respectively.

Some of the predicted discharges are made on the basis of conservative modelling using the GALE code. This modelling can significantly overestimate some of the radionuclides released, particularly for fission products. There is now an updated methodology available (US NRC Regulatory Guide 1.112); some of the vendors' predicted discharges are currently being modified.

**Table 6.3 Comparison of predicted discharges.**

| Design | Predicted liquid discharge (GBq/GWeh) | Predicted airborne discharge (GBq/GWeh) |
|---|---|---|
| AP1000 | 3.82 | 43.1 |
| EPR | 3.58 | 0.13 |
| ESBWR | 0.0.382 | 11.4 |
| ACR-1000 | 12.6 | 6.97 |

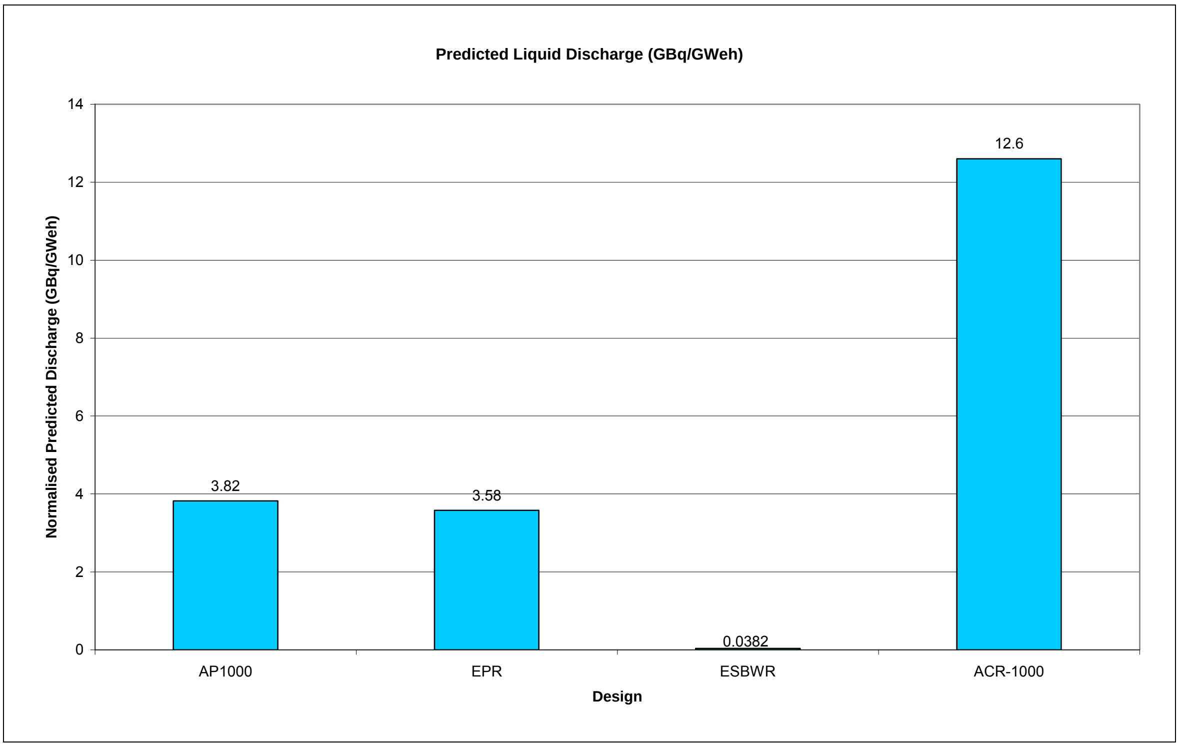

Figure 6.29 Predicted liquid discharges.

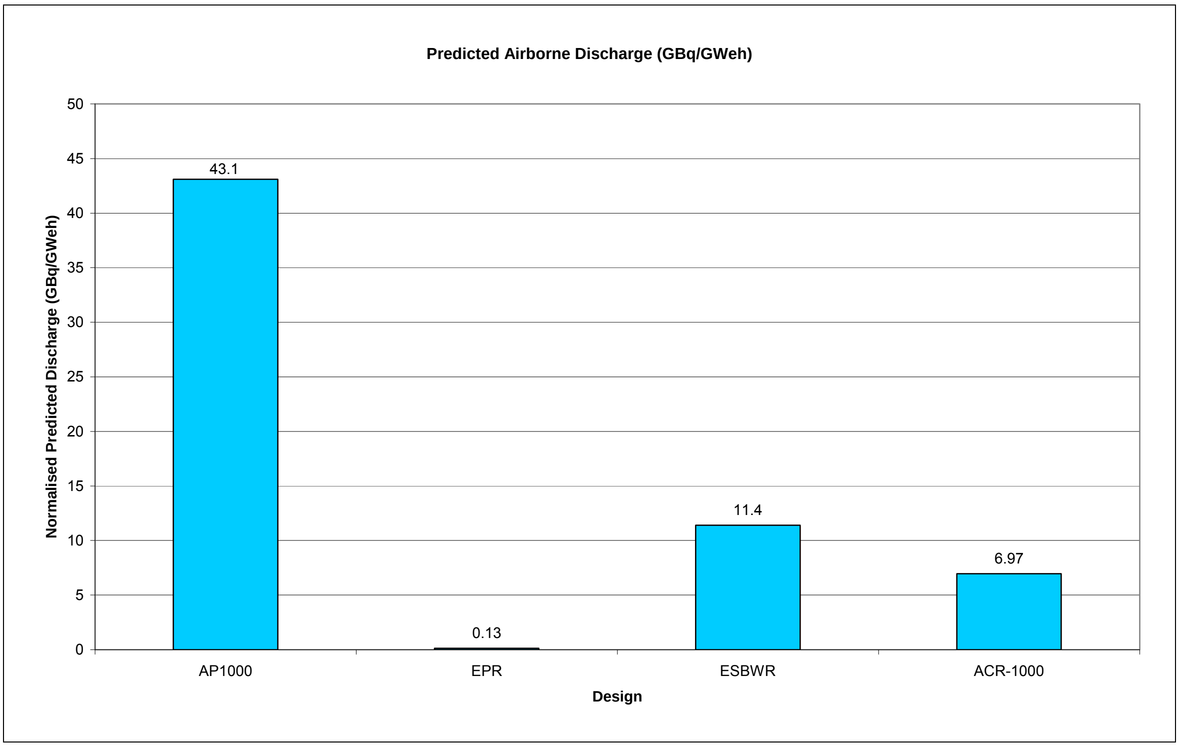

Figure 6.30 Predicted airborne discharges.

A more detailed analysis is recommended to provide a better understanding of the radiological significance of the above discharges.

### 6.4.12 Comparing predictions with to historic discharges

Figure 6.31 to Figure 6.38 show a comparison of the predicted discharges and the historical discharges from the predecessor reactors studied. The comparison produces the following observations:

i. AP1000

   Aside from the relatively higher liquid discharges from Sizewell B and an increased liquid discharge from Byron in 2004, the predicted liquid discharge from the AP1000 is in line with the historical reported discharges.

   The predicted airborne discharge, however, is generally higher than that experienced by the predecessor reactors.

ii. EPR

   Except for an increased liquid discharge from Chooz in 1998, the historical discharges from EPR predecessors are generally about 1.5 GBq/GWeh lower than the predicted value for the EPR design.

   Historical airborne discharges, especially in the 1990s, are significantly higher than the airborne discharge predicted for the EPR design. However, the reactors in this class that indicate the higher discharges are not immediate predecessors to the EPR.

iii. ESBWR

   Historical liquid discharges from ESBWR predecessor reactors are higher than the predicted liquid discharge from the ESBWR design for a number of reactors (see Figure 6.35).

   Historical airborne discharges, however, are more than 9 GBq/GWeh lower than the predicted airborne discharge from the ESBWR design.

   These observations suggest that the ESBWR design favours airborne discharges to liquid discharges.

iv. ACR-1000:

   Most predecessor reactors considered in this study have experienced significantly higher discharges than those predicted to arise from the ACR-1000 design (see Figure 6.37 and Figure 6.38).

   Darlington and Pickering B are the only two predecessor reactor sites where liquid discharges are below those predicted from the ACR-1000 design.

It is also recognised that the requirements for reporting and predicting discharges depend on the policies of the reactor power station, the design vendors and the regulatory regime within the operating nation (e.g. the ACR-1000 data does not include a prediction for particulates). Such variations need to be taken into account for a fair comparison between discharges to be made.

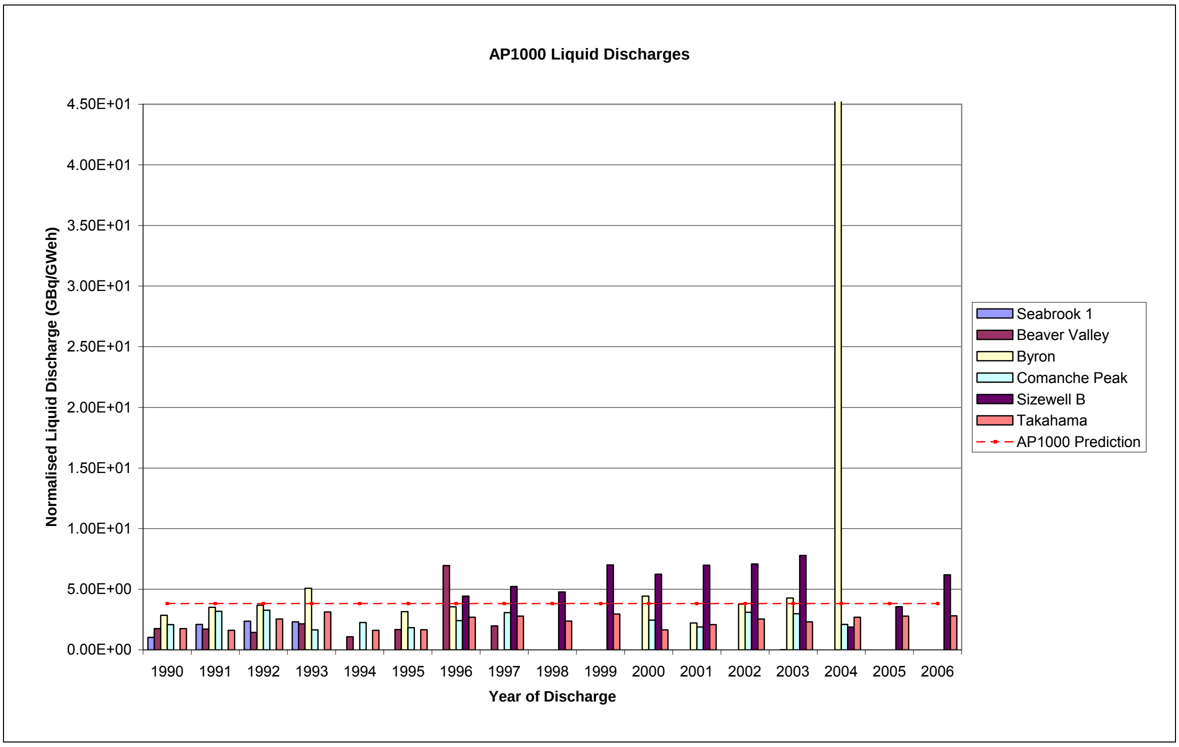

Figure 6.31 Historical liquid discharges from AP1000 predecessors and the predicted discharge for the AP1000 design.

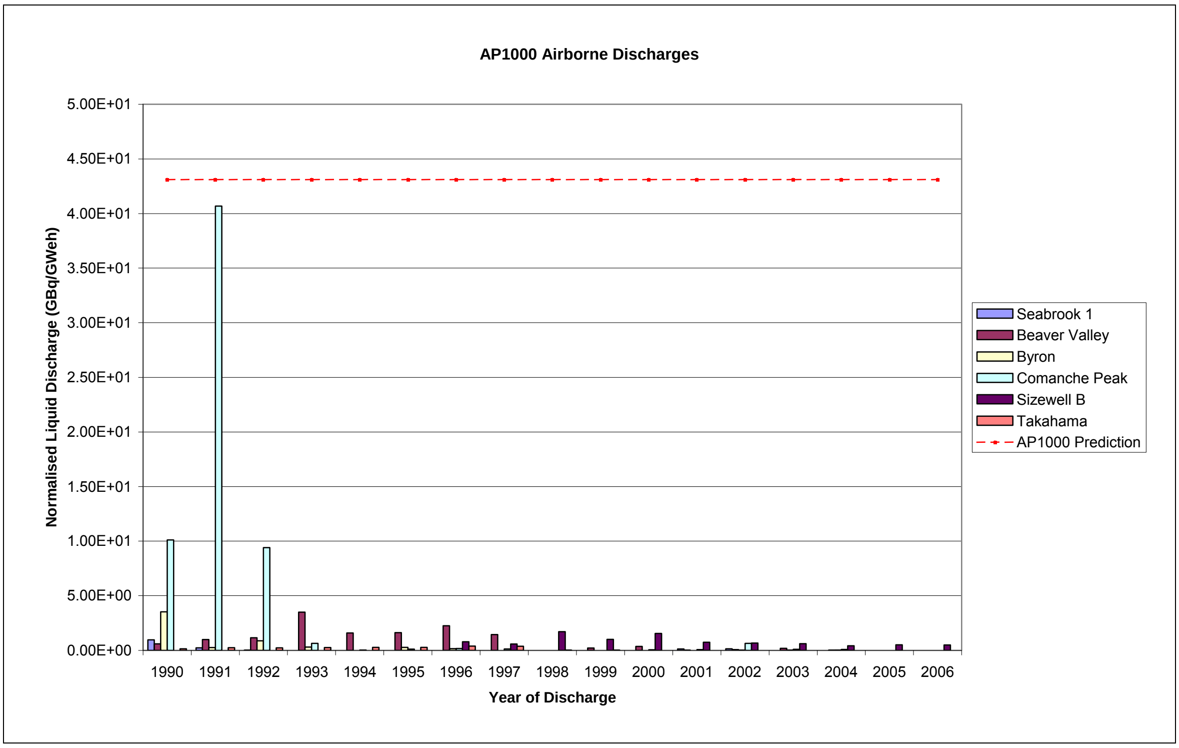

Figure 6.32 Historical airborne discharges from AP1000 predecessors and the predicted discharge for the AP1000 design.

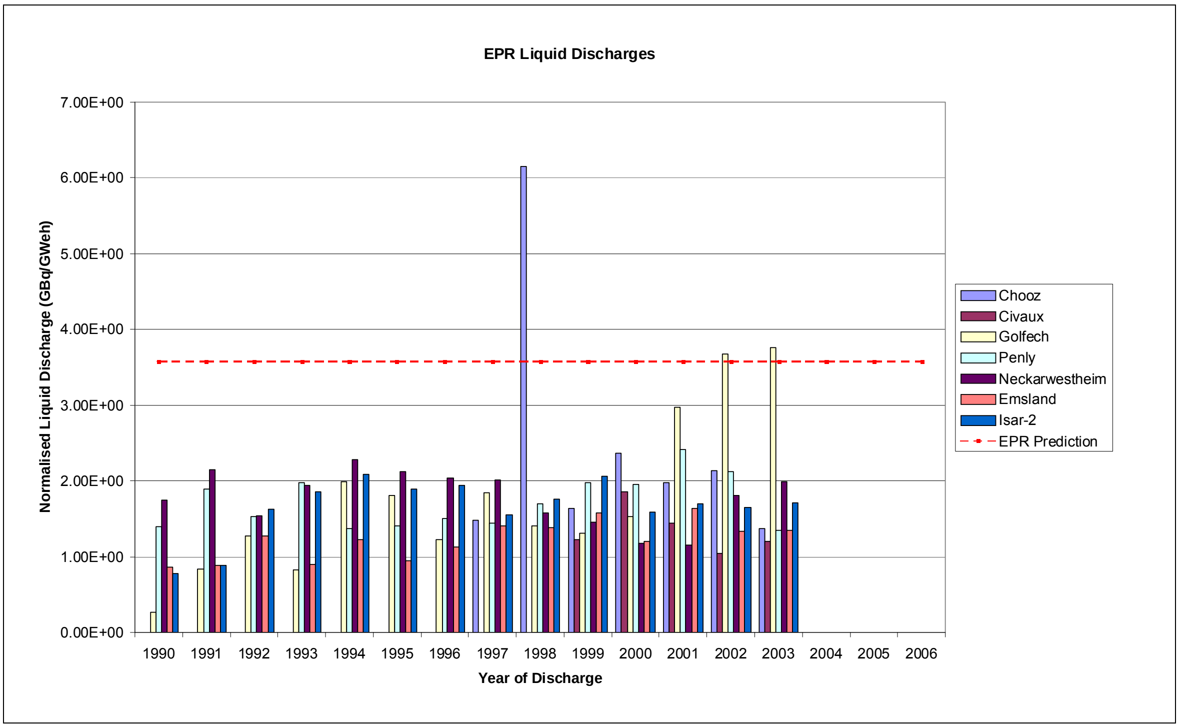

Figure 6.33 Historical liquid discharges from EPR predecessors and the predicted discharge for the EPR design.

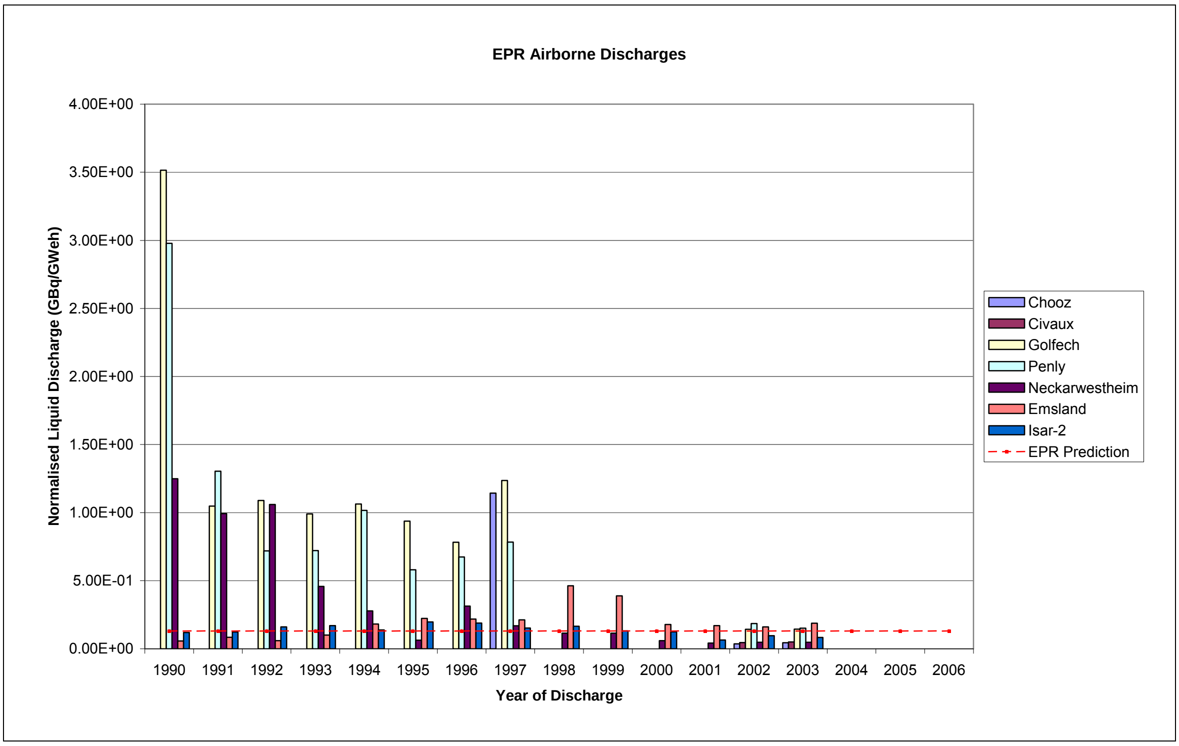

Figure 6.34 Historical airborne discharges from EPR predecessors and the predicted discharge for the EPR design.

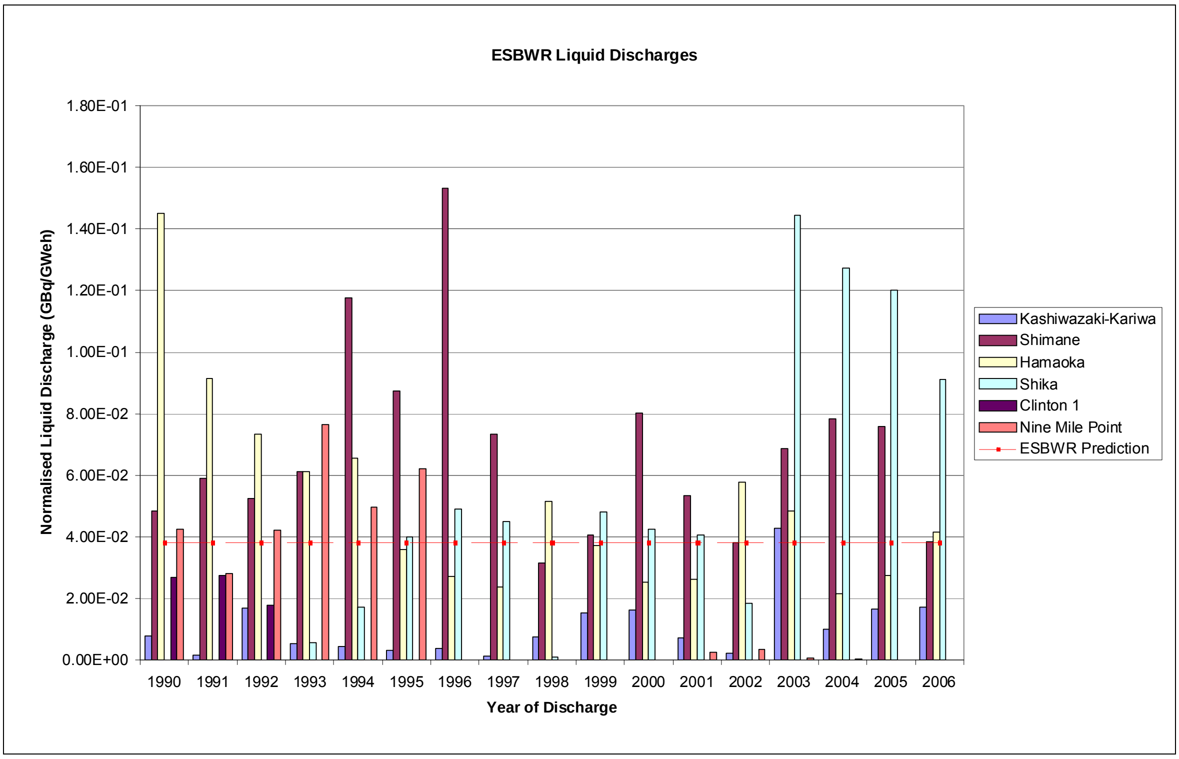

Figure 6.35 Historical liquid discharges from ESBWR predecessors and the predicted discharge for the ESBWR design.

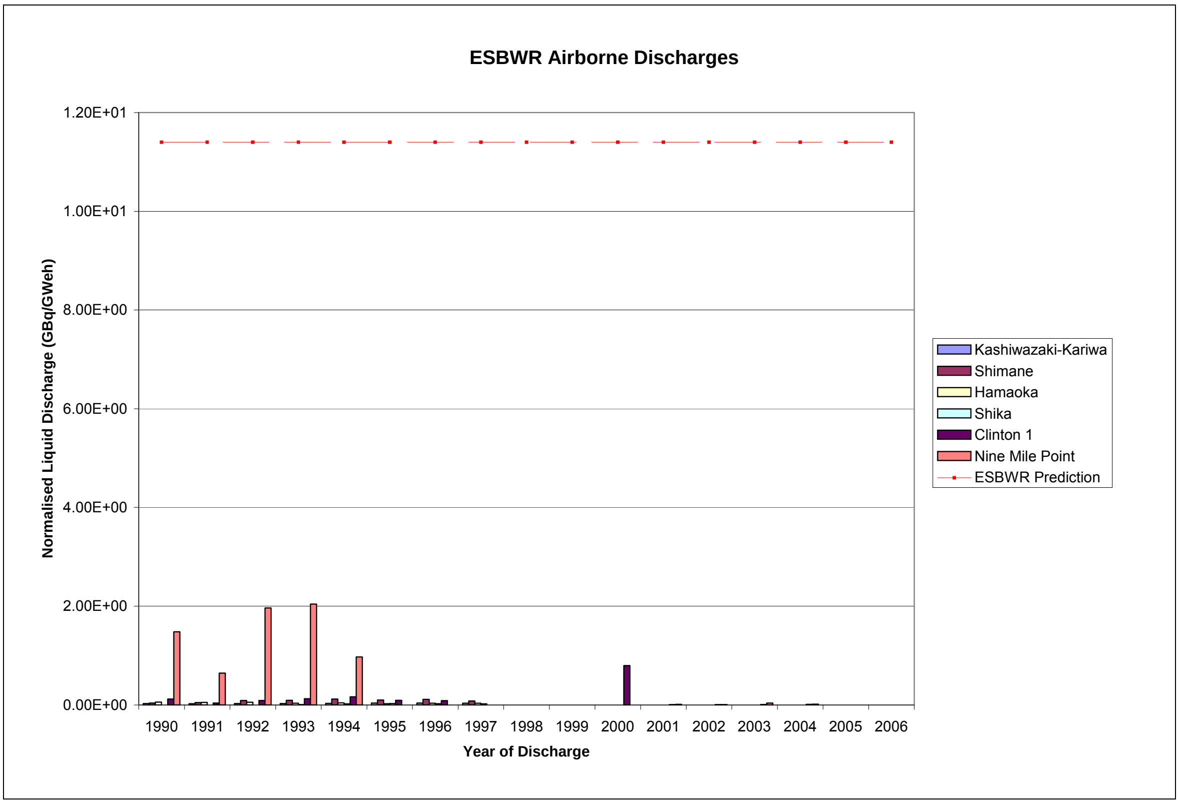

Figure 6.36 Historical airborne discharges from ESBWR predecessors and the predicted discharge for the ESBWR design.

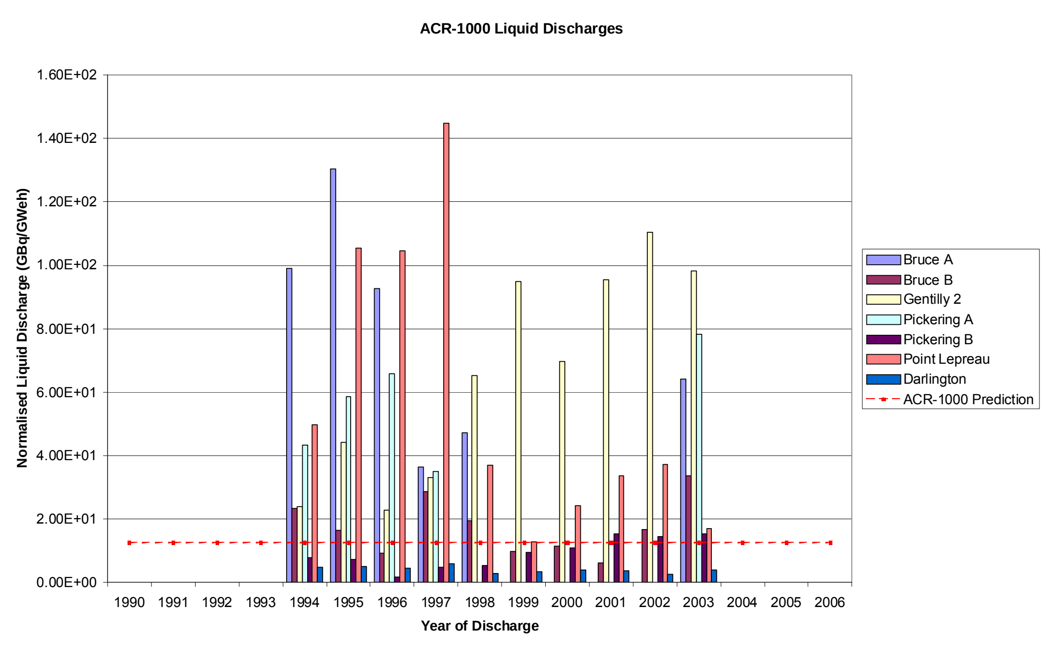

Figure 6.37 Historical liquid discharges from ACR-1000 predecessors and the predicted discharge for the ACR-1000 design.

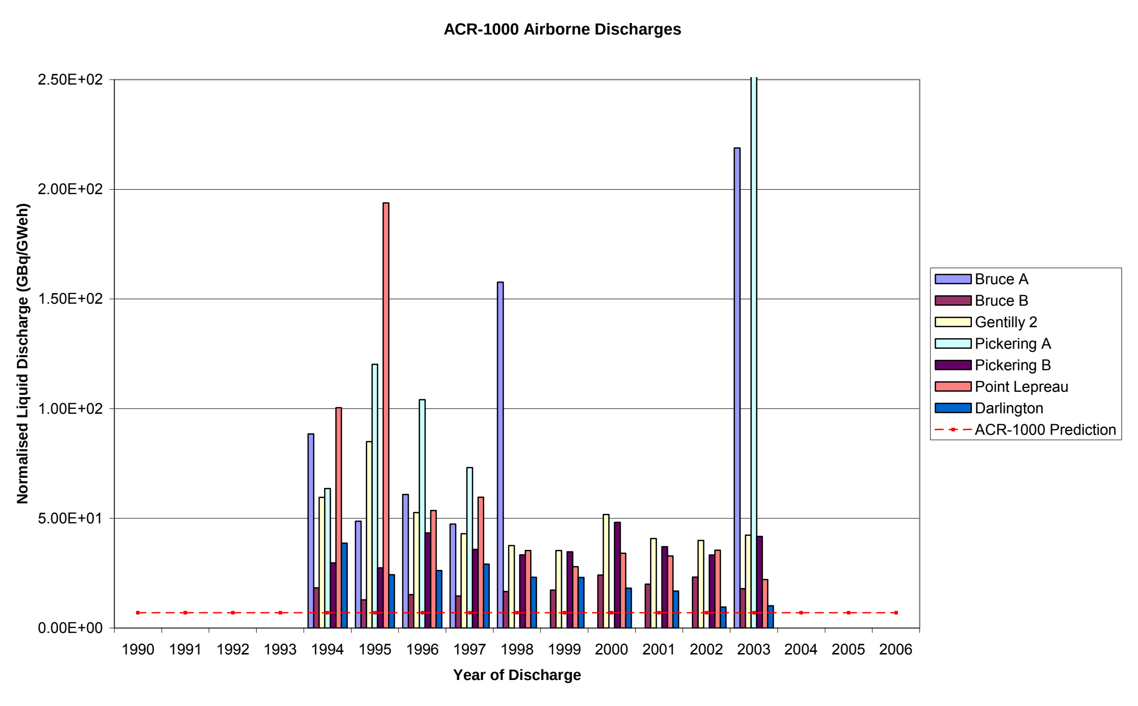

Figure 6.38 Historical airborne discharges from ACR-1000 predecessors and the predicted discharge for the ACR-1000 design.

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# Appendix A: Details of reactor designs

The information in this appendix is based on information provided in the GDA submissions (HSE, 2008) for each of the four proposed designs as well as on other information sources, where referenced.

The four generic reactor designs submitted for GDA are:

- the AP1000, submitted by Westinghouse;
- the European Pressurised Reactor (EPR), submitted by Electricité de France (EDF)/Areva;
- the Economic Simplified Boiling Water Reactor (ESBWR), submitted by GE-Hitachi;
- the ACR-1000, submitted by Atomic Energy of Canada Ltd (AECL).

The manufacturers claim that these new designs all aim to improve safety, efficiency and reliability. They all use water technology for neutron moderation and heat removal. The first three designs use light water reactor (LWR) technology whereby light water acts as the moderator and as the method for heat removal from the core. The fourth design uses heavy water as the moderator and light water for heat removal. Of the three LWR designs, two (the AP1000 and the EPR) are PWRs and one (the ESBWR) is a boiling water reactor (BWR).

In a PWR heat removal is achieved using two coolant circuits – a primary and a secondary circuit. The primary coolant circuit is maintained under high pressure to ensure that the water remains in the liquid phase. The primary coolant circuit, which is also the moderator, is separated from the secondary circuit. It contains radioactive material that might arise from leaking fuel pins and corrosion of activated reactor internal structures. Steam to drive the electricity generating turbines is generated in the secondary coolant circuit.

In a BWR, heat removal is achieved by a single coolant circuit; although it is under pressure, the water is allowed to boil in the core region, generating steam to drive the electricity generating turbo-alternators.

The fourth reactor design is a CANDU reactor which has been developed in Canada and uses heavy water (deuterium) and low enriched uranium. This technology also has two coolant circuits. The primary circuit contains heavy water under high pressure in tubes passing through a calandria holding the heavy water moderator; the primary coolant is thus separated from the moderator heavy water. Again, steam to drive the electricity generating turbines is generated in the secondary coolant circuit.

The discharges predicted for each of the proposed designs are summarised and compared in Appendix B.

The abatement techniques proposed in each of the generic designs are summarised and compared in Appendix C.

Other features of each design are provided in the following sections.

Since this work commenced, AECL has withdrawn from the GDA process. However, as the data had already been collated and the analysis was well advanced, it has been retained in this study.

# A 1 Westinghouse AP1000

## A 1.1 Description of the proposed AP1000

The AP1000 is a two loop PWR designed by Westinghouse. This design is described further in Section A 1.3. It has a 157-fuel-assembly core and received final design approval from the US Nuclear Regulatory Commission (NRC) in September 2004 and Design Certification in December 2005.

## A 1.2 The operation of the Westinghouse PWR

PWRs have two categories of coolant loop: primary and secondary. The primary coolant system consists of the reactor vessel and two or more primary coolant loops. The purpose of the primary coolant loop is to transfer heat from the reactor core to the secondary coolant circuit (shown blue in Figure A.1), which in turn supplies steam to a number of electricity generators. The primary coolant loop is kept under pressure (about 15.5 MPa) to prevent the formation of steam in the primary circuit. The separation between the primary and secondary coolant circuits means that any radioactive contamination from the reactor core is contained within the primary coolant loop, thereby preventing the contamination of the steam generators and turbines.

In the steam generators, the water in the secondary coolant circuit is converted into steam, which is then fed into the electricity generating turbines, which are connected to the national grid. This part of the process is similar to the generating step in coal or gas fired power stations and is the conventional part of a nuclear power station.

PWRs use low enriched uranium (3–4 per cent U-235) as fuel. This fuel is in the form of pellets of uranium dioxide (also known as urania or uranic oxide) contained in zirconium-clad fuel pins in fuel assemblies. The structure of a typical fuel assembly for existing PWRs is illustrated in Figure A.2[2]. Although not shown in Figure A.2, the fuel assembly also houses the control rods (neutron absorbers), which are used to control the power level in the core.

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[2] Figure A.1 shows a generic design that is most relevant to the predecessors to the proposed Westinghouse AP1000. The proposed AP1000 design differs in some fundamental parameters, such as the fact that the AP1000 design has 157 fuel rods compared to the predecessors that have 264 fuel rods. Details of the design differences are summarised in Appendix B, Table B.1

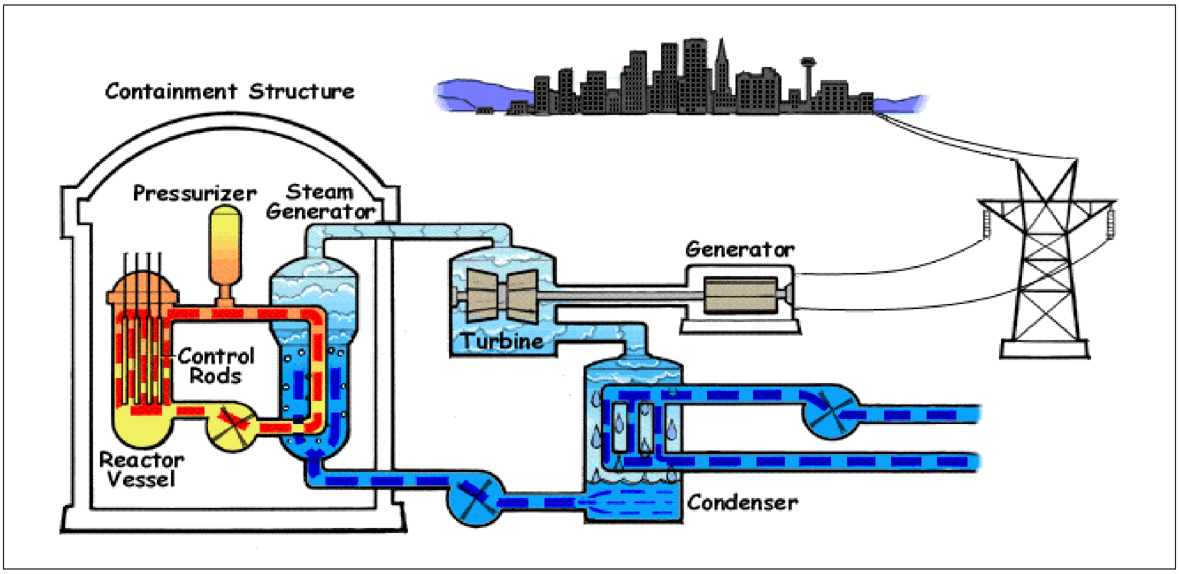

**Figure A.1 Simplified schematic of a Pressurised Water Reactor (PWR) (NRC, 2007).**

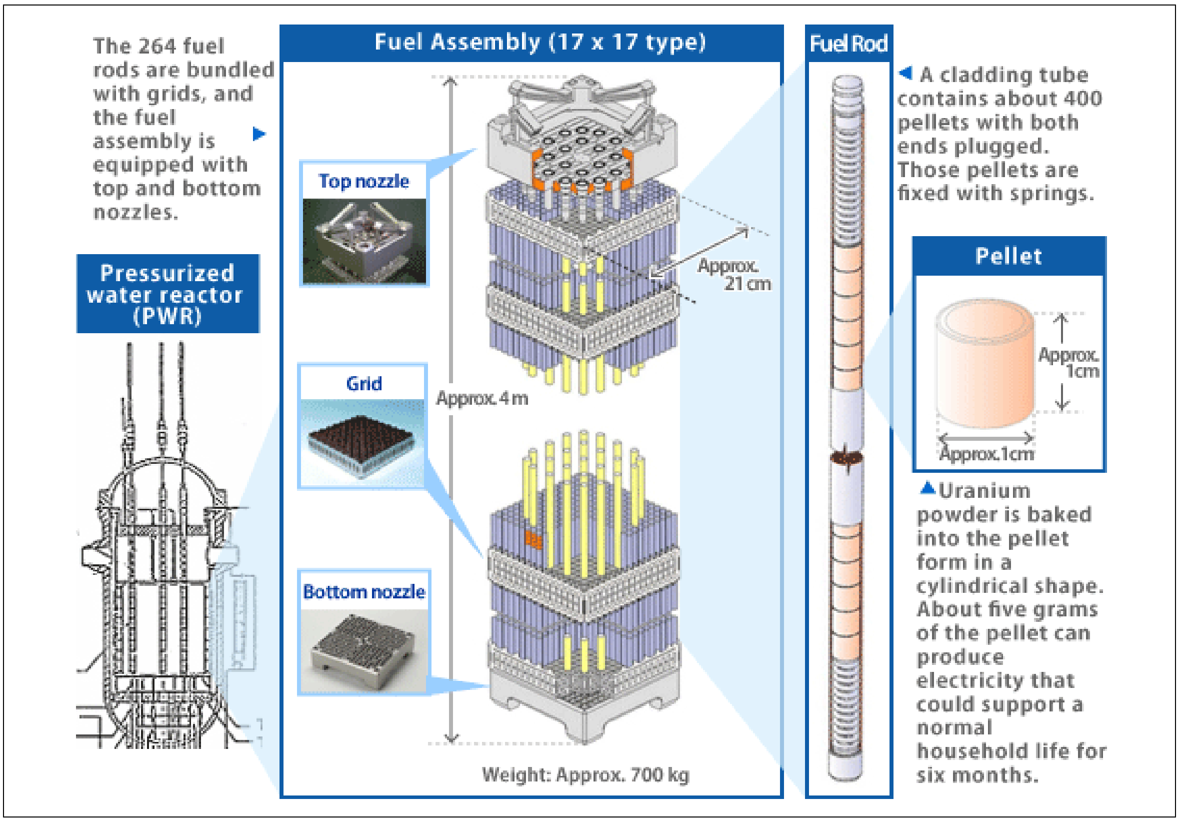

**Figure A.2 The PWR fuel assembly (NFI, 2008).**

## A 1.3 Features of the AP1000

The AP1000 design is the latest development of the Westinghouse PWR designs and is conceptually the same as previous PWR designs (e.g. Sizewell B).

The AP1000 features passive safety systems, relying on natural phenomena (such as gravity and heat circulation) instead of operator action or electronic feedback.

The AP1000 design has fewer fuel assemblies in the core – 157 fuel assemblies (NRC, 2002) compared to more than 200 in the predecessor Westinghouse designs.

The AP1000 design also has fewer control assemblies in the core – 53 control assemblies rather than the 83 found in the predecessor Westinghouse design.

A more detailed comparison of the design parameters of the AP1000 with those of a typical two-loop plant in the USA is provided in Appendix B, Table B.1.

## A 1.4 Nature and quantity of discharges from the AP1000

(a) Liquid discharges

Radioactive liquid discharges from the AP1000 originate both from the primary coolant circuit (from leakages and the adjustment of the concentration of the reactor coolant boron), the secondary coolant circuit (from steam generator blowdown processing and leakages), the fuel pool and treatment of fuel pool water.

The radioactive liquid waste system for the AP1000 provides the capability to reduce the quantities of radionuclides released through the use of demineralisation and a time delay prior to release to allow some decay of short-lived nuclides. This waste treatment system processes contaminated liquids using an upstream filter followed by four ion exchange resin vessels placed in series.

The predicted quantities of liquid radioactive wastes generated by an AP1000 unit are (Westinghouse, 2008):

- predicted tritium release: 37.4E+03 GBq per year;
- predicted releases of other radionuclides: 9.48 GBq per year.

These releases have been predicted by the PWR-GALE code (Gaseous and Liquid Effluents from Pressurised Water Reactors). The code models releases which use source terms derived from data obtained from the experience of operating PWRs. The predicted releases include an adjustment of 5.92 GBq per year to account for anticipated operational occurrences (such as operator errors) resulting in unplanned releases. It must be noted that the above predicted discharges have been provided by Westinghouse as part of their GDA submission and have not been independently validated.

(b) Gaseous discharges

Radioactive gaseous discharges from the AP1000 originate from:

- ventilation discharges from the primary containment where radioactivity has accumulated following:
  - the leakage of reactor coolant;
  - activation of naturally occurring Ar-40 in the atmosphere to form radioactive Ar-41;
- ventilation discharges from the auxiliary building, where radioactivity has accumulated due to leakages from process streams;
- ventilation discharges from the turbine building;
- the condenser air removal system (gaseous activity entering the secondary coolant as a result of primary to secondary leakage via this pathway);

- the radioactive gaseous waste system (i.e. wastes from the degasifier in the radioactive liquid waste system and from vents in the reactor coolant drain tank).

The radioactive gaseous waste system includes a guard bed and delay beds. The guard bed consists of activated carbon and protects the delay beds from abnormal moisture or chemical contaminants. Under normal operating conditions, the guard bed increases the delay time for xenon and krypton and prevents iodine from entering the system.

(c) Predicted annual discharges

The predicted quantities of gaseous radioactive wastes generated by an AP1000 unit are (Westinghouse, 2008):

- predicted tritium release: 1.3E+04 GBq per year;
- predicted carbon-14 release: 2.7E+02 GBq per year;
- predicted noble gases release: 4.08E+05 GBq per year;
- predicted halogens release: 1.92E+01 GBq per year;
- predicted particulates release: 1.75 GBq per year.

These releases have been predicted by the PWR-GALE code (Gaseous and Liquid Effluents from Pressurised Water Reactors). The code models releases using source terms derived from data obtained from the experience of operating PWRs. It must be noted that the predicted discharges have been provided by Westinghouse as part of their GDA submission and have not been independently validated.

# A 2 EDF/Areva EPR

## A 2.1 Description of the proposed EPR design

The European Pressurised Reactor (EPR) is based on the French N4 reactor (examples of which are in operation at Chooz and Civaux) and the German Konvoi reactor (in operation at Neckarwestheim-2, Emsland and Isar-2). The EPR is also sometimes called the Evolutionary or Enhanced Pressurised Water Reactor. The EPR design is based on the combined design and operational experiences of Framatome ANP and Siemens KWU.

Two EPR units are currently under construction: one in Finland (Olkiluoto-3); and, one in France (Flamanville-3) and two have been ordered in China (Taishan). The design has also been submitted to the NRC in the USA for design approval and certification, a process that can take about five years.

## A 2.2 The operation of the EPR

EPRs operate in essentially the same way as the Westinghouse PWR, as described in Section A 1.2. The proposed EPR design is a four-loop plant with similar configurations to those of currently operating PWRs. EPRs also use low enriched uranium (3–4 per cent U-235) as fuel.

## A 2.3 Features of the EPR

The EPR incorporates some new features designed to reduce radioactive liquid waste. The EPR allows increased recycling of aerated primary liquid effluents back to the primary circuit. While the current PWRs require multiple transfers and redirection of effluents through various sumps in the plant to effect selective treatments, the EPR design improves the selective collection of floor and chemical drains (three categories of floor drains) to facilitate segregation and selective treatments.

In addition, there are some design features that reduce radioactive gaseous wastes. In the current 1,300 MWe plants, only selected plant areas in the Nuclear Auxiliaries Building (BAN) can be routed to iodine traps, but in the EPR all of the ventilation systems for the BAN, the Safeguard Building (BAS) and Fuel Building (BK) rooms can be routed to iodine traps prior to discharge.

In the current 1,300 MWe plants, the intermediary primary liquid effluent (TEP) tank is flushed. This is the main source of radioactive gaseous discharge. In the EPR design, there is no flushing of the intermediary TEP tank; the main source of radioactive gaseous discharges is evaporation from the spent fuel pool. This aspect of the EPR design is similar to the EDF 900 MWe and N4 reactors (the immediate predecessor to the EPR design).

Penly and Golfech are examples of the P4 series of PWRs which are the immediate predecessors to the N4 series. The N4 series has incorporates several different design features compared to the earlier P4 model, including the computerised control and instrumentation system, and more compact steam generators and primary pumps (EDF, 2005).

A more detailed comparison of the EPR design parameters with those of the French N4 plant and the German Konvoi plant is provided in Appendix B, Table B.2 (EDF/AREVA, 2008a).

## A 2.4 Nature and quantity of discharges from the EPR

Sources of radioactive discharges from the EPR are:

- nitrogen-16 (by activation of oxygen-16 in water);
- nitrogen-17 (by activation of oxygen-17 in water);
- tritium (by activation of boron, lithium or deuterium);
- argon-41 (by activation of argon-40);
- carbon-14;
- activated corrosion products (Mn-54, Co-58, Fe-59, Co-60, Cr-51, Ni-63, Ag-110, Sb-124, Sb-122);
- fission products (noble gases, strontium, iodides and caesium).

(a) Liquid discharges

The EPR will generate two types of radioactive liquid waste, classified according to the source of the waste

i. Liquid waste from the primary coolant system.

   This waste contains dissolved fission gases (xenon, iodine, etc.), fission products (caesium, etc.), activation products (cobalt, manganese, tritium, carbon-14, etc.), and chemical substances such as boric acid and lithium hydroxide.

ii. Liquid waste from systems connected to the primary coolant system.

   This waste stream includes:

- discharges which contain radioactivity but do not contain hazardous chemicals;
- discharges which contain radioactivity and hazardous chemicals;
- discharges with a very low level of radioactivity collected by the floor drains.

The EPR systematically collects this waste and treats it, retaining most radioactivity in a solid form. The treated liquid will then be stored in tanks where it will be monitored for both radioactivity and chemical levels before being discharged.

In addition, the EPR will contain ion exchange systems in the CVCS to remove selected dissolved activated materials prior to returning the treated coolant back to the primary circuit or removing it for further treatment in other down-line systems.

The EPR offers increased recycling of aerated primary liquid effluents back to the primary circuit. This recycling is possible because the off gasses from these effluents, that contain air, can be readily handled in the radioactive gaseous waste system. This is especially important during shutdown periods (when the primary coolant is partially open to air).

The EPR is designed to also reduce the discharge of tritium, by reducing boron concentrations and changing lithium hydroxide concentrations in the primary coolant chemistry.

(b) Gaseous discharges

The EPR will incorporate a number of design features to reduce the generation of radioactive gaseous waste. The EPR will use containment within the plant and recycling where possible; it will treat waste gases to ensure that most radionuclides are removed and contained within solid filters. Treated gases will be held to allow decay of short lived radionuclides and will be monitored before discharge via a stack.

All of the ventilation systems for the BAN (Nuclear Auxiliary Building), BAS (Safety Auxiliary Building), and BK (Fuel Building) rooms pass through HEPA filters that can be routed to the iodine traps prior to discharge.

The EPR design uses a gaseous waste processing system (TEG), which is the most recent development to the German Konvoi reactors. In normal operation, this system enables the treatment of aerated liquid effluent in a semi-closed loop. The TEG integrates various features, namely:

- sharing the intermediary primary liquid effluent (TEP) and the Reactor Boron and Water Makeup (REA) tank covers to limit the volume of the gaseous waste in normal operation (constant gaseous balance when water is moving);
- continuous nitrogen flushing of the tank ullages and head spaces to lower the hydrogen content and increase standardisation and flexibility in the treatment of off gases from tanks etc, whether their compositions are dominated by hydrogen or oxygen;
- recycling gases to limit the volume of the gaseous waste in normal operation;
- recombination of hydrogen in the off gas from tanks etc into water;
- decaying the short-lived gases (mainly xenon and krypton) from the TEG system on absorbent charcoal delay beds;
- automatic discharge into the discharge stack as soon as a threshold pressure (that can be modified (the set point) according to the volumes of gas to be treated), is reached.

(c) Predicted annual discharges

The predicted annual liquid discharges from the EPR are (EDF/AREVA, 2008b):

- predicted tritium release: 52,000 GBq;
- predicted carbon-14 release: 23 GBq;
- predicted halogens release: 0.007 GBq;
- predicted release of other liquid discharges: 10 GBq.

The predicted annual gaseous discharges from the EPR are as follows (EDF/AREVA, 2008b):

- predicted tritium release: 500 GBq;
- predicted carbon-14 release: 350 GBq;
- predicted halogens release: 0.05 GBq;

- predicted noble gases release: 800 GBq;
- predicted release of other airborne discharges: 0.004 GBq.

The predictions exclude any operating contingencies. It should also be noted that the predicted discharges have been provided by EDF/Areva as part of their GDA submission and have not been independently validated.

# A 3 GE-Hitachi ESBWR

## A 3.1 Description of the proposed ESBWR design

The Economic Simplified Boiling Water Reactor (ESBWR) is a development by General Electric (GE) that builds on its Advanced Boiling Water Reactor (ABWR). The ABWR is licensed in the USA, Japan and Taiwan. Although commissioning of a number of ABWRs is in progress in Taiwan, the only ABWR units presently in operation are in Japan, at the Hamaoka, Kashiwazaki-Kariwa and Shika reactor power stations.

## A 3.2 The operation of a GE-Hitachi BWR

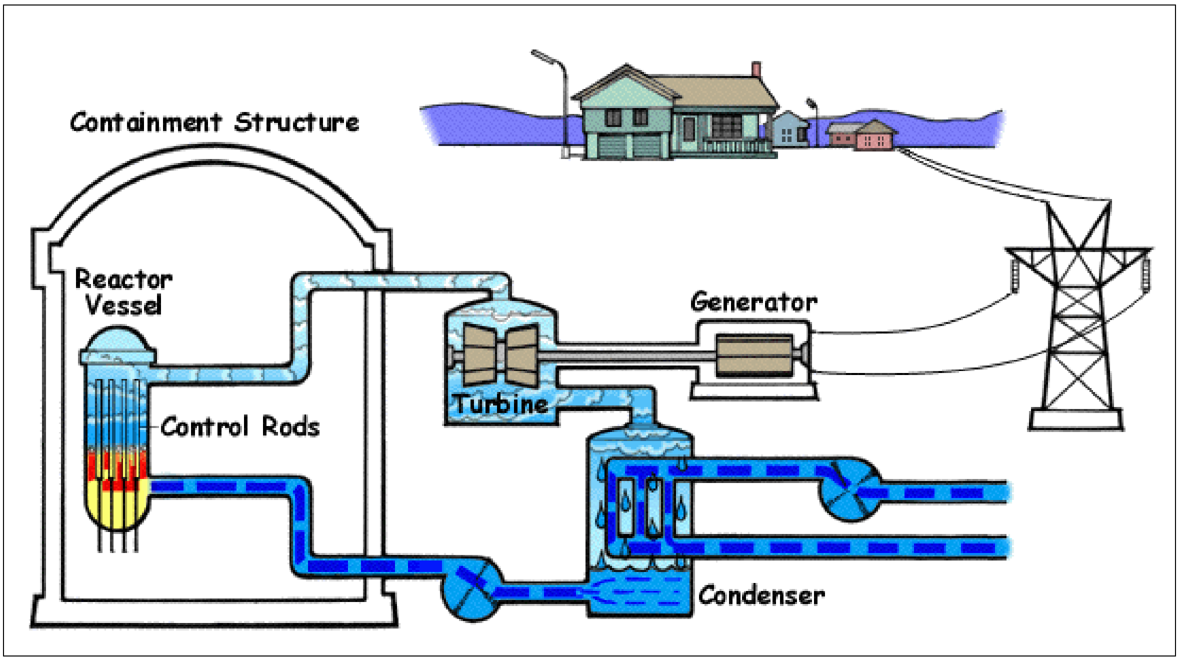

**Figure A.3 Simplified schematic of a BWR (Wikipedia, 2008a).**

BWRs have a single coolant circuit that transfers heat away from the reactor core by raising steam in the reactor core. This steam is then used to drive the electricity generating turbines. The reactor vessel is kept under pressure (about 7 MPa, which is lower than the pressure maintained in a PWR). This single coolant circuit concept does not prevent radioactive contamination of the turbines and condensers. However in comparison to PWRs, BWRs have fewer pipes, welds and components.

ESBWR predecessor designs use recirculation pumps (not shown in Figure A.3), which control the void coefficient of reactivity (which in turn controls the power) in the reactor core. The recirculation pumps blow voids (steam bubbles) out of the reactor core leading to increased moderation and therefore increased reactivity.

In contrast to PWRs and most other reactor types, control rods in BWRs are inserted from below the reactor pressure vessel.

The ESBWR operates on low enriched uranium (~3–4 per cent U-235). A typical BWR fuel assembly is shown in Figure A.4.

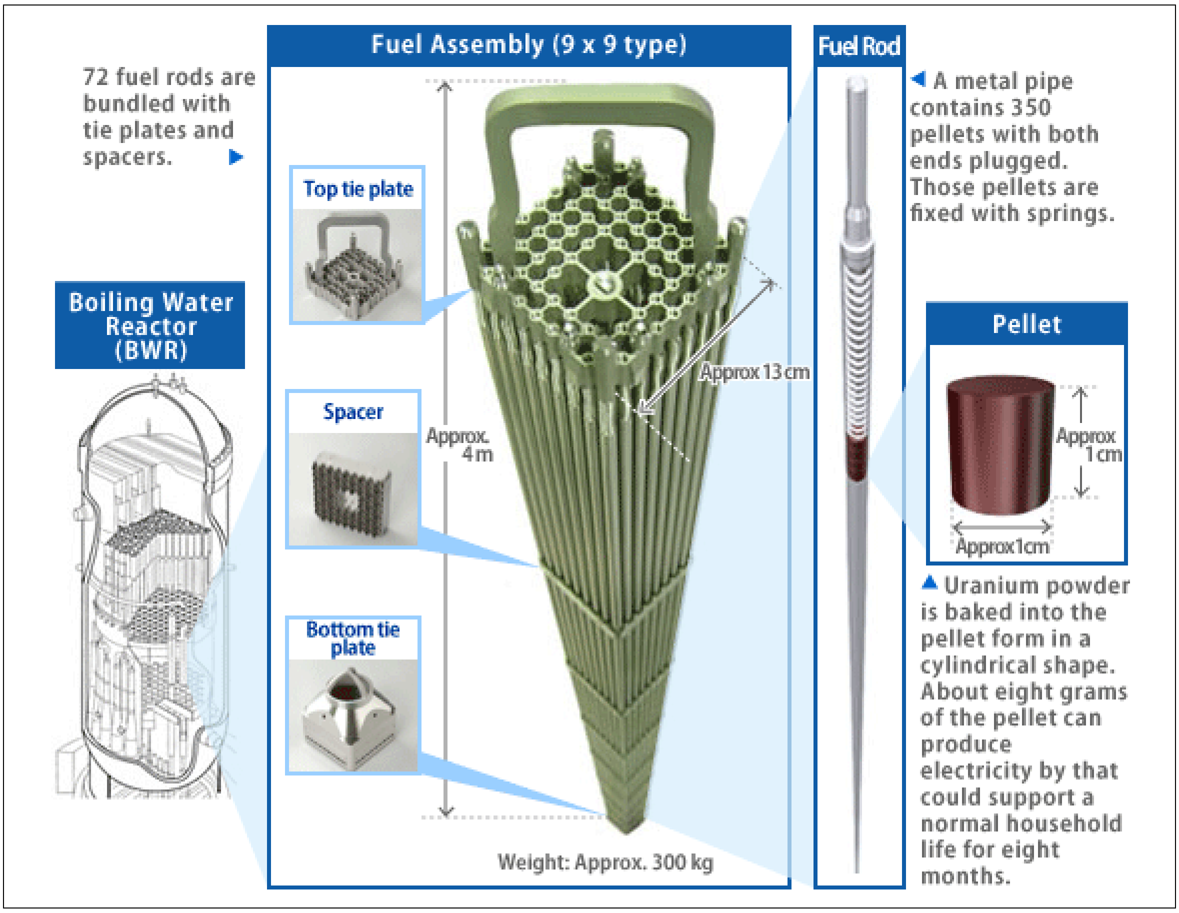

**Figure A.4 A BWR fuel assembly (GE-Hitachi, 2008).**

## A 3.3 Features of the ESBWR

The key features of the ESBWR are:

- a gravity-driven cooling system (GDCS);
- use of natural circulation instead of recirculation pumps within the reactor vessel;
- the elimination of 11 systems from previous designs;
- 25 per cent fewer valves and motors compared to previous designs;
- passive safety features such as containment cooling, natural circulation and debris resistant fuel.

A detailed comparison of the ESBWR design parameters and those of the Japanese ABWR and BWR plants and the American BWR plants is provided in Appendix B, Table B.4.

## A 3.4 Nature and quantity of discharges from the ESBWR

(a) Liquid discharges

The predicted annual liquid discharges from the ESBWR are as follows (GE-Hitachi, 2008):

- predicted tritium release: 5.18E+02 GBq;
- predicted release of other liquid discharges: 3.62 GBq.

(b) Gaseous discharges

The predicted annual airborne discharges from the ESBWR are as follows (GE-Hitachi, 2008):

- predicted tritium release: 2.8E+03 GBq;
- predicted carbon-14 release: 3.54E+02 GBq;
- predicted iodine-131 release: 1.51E+01 GBq;
- predicted noble gases release: 1.53E+05 GBq;
- predicted release of other airborne discharges: 3.56 GBq.

It must be noted that the predicted discharges have been provided by GE-Hitachi as part of their GDA submission and have not been independently validated.

# A 4 AECL ACR-1000

## A 4.1 Description of the proposed ACR-1000 design

The AECL ACR-1000 is a pressure tube heavy water reactor (PHWR) designed by Atomic Energy of Canada Ltd (AECL). The ACR-1000 is the successor to the CANDU-6 series of PHWRs, also designed by AECL.

Canada's fleet of nuclear reactors consist solely of CANDUs. The design has been exported to South Korea, China, Romania and India.

## A 4.2 Operation of the AECL PHWR (CANDU reactor)

The CANDU (CANada Deuterium Uranium) reactor is a PHWR with primary and secondary coolant circuits. A schematic of the CANDU reactor is shown in Figure A.5.

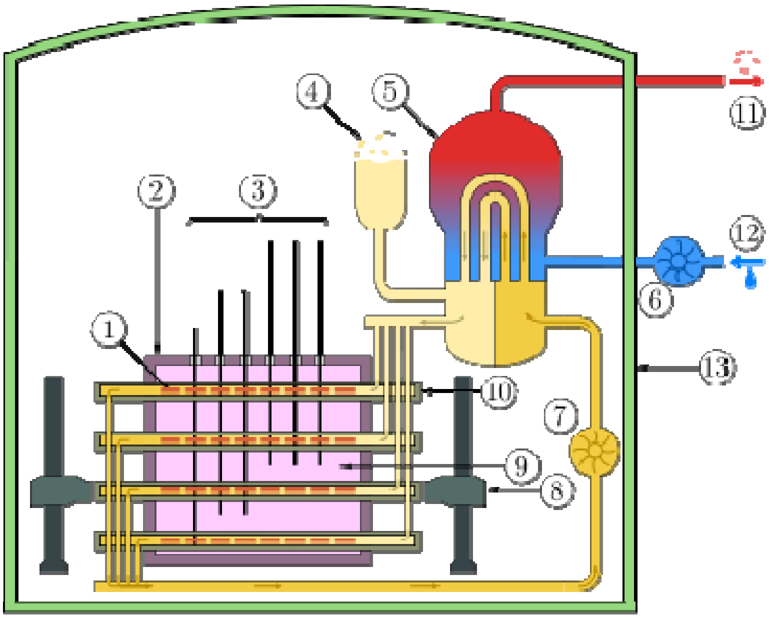

**Figure A.5 Simplified schematic of a CANDU reactor (Wikipedia, 2008b).**

In contrast to LWRs (Light Water Reactors), CANDU reactors feature a horizontal fuel arrangement. The separation between fuel bundles (1) is also larger when compared to LWRs. This fuel arrangement stems from the use of heavy water (deuterium) as the moderator in CANDUs. The diffusion length in heavy water (deuterium) is greater than in light water (hydrogen) and thus the spacing between fuel bundles is greater. The use of deuterium allows the CANDU reactors to operate with natural uranium (0.7 per cent U235). A CANDU fuel bundle is shown in Figure A.6 below.

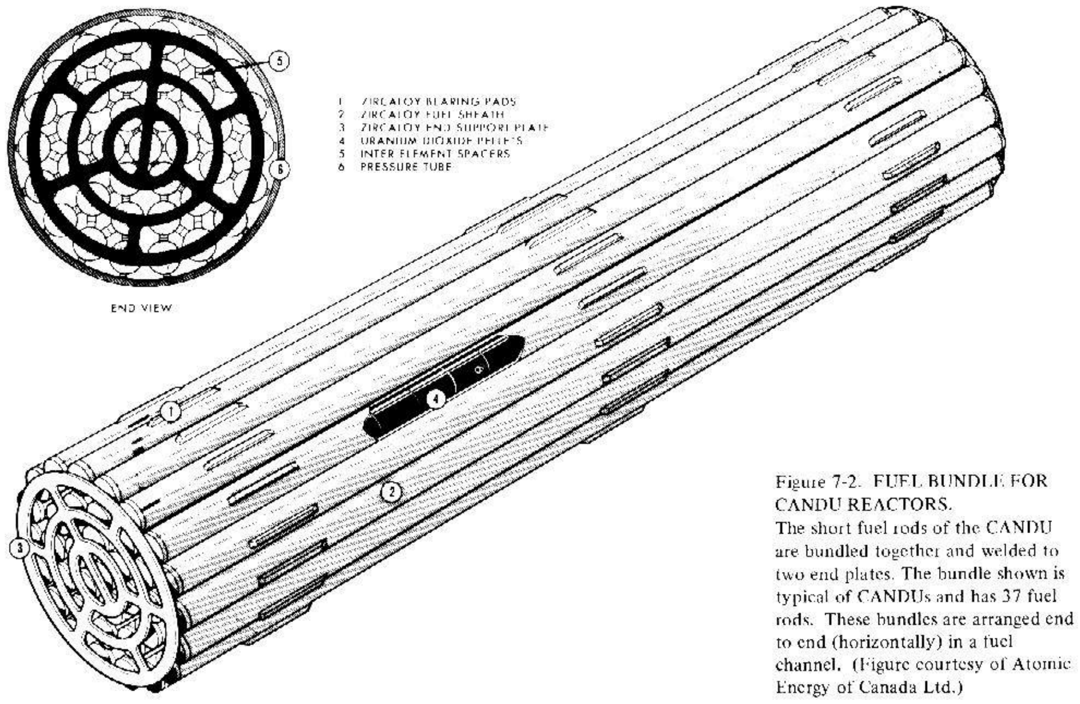

Figure 7-2. FUEL BUNDLE FOR CANDU REACTORS. The short fuel rods of the CANDU are bundled together and welded to two end plates. The bundle shown is typical of CANDUs and has 37 fuel rods. These bundles are arranged end to end (horizontally) in a fuel channel. (Figure courtesy of Atomic Energy of Canada Ltd.)

**Figure A.6 The CANDU fuel assembly (Nero, 1979).**

A calandria (2) (shown in Figure A.5) contains the heavy water moderator; the horizontal fuel channels run through this calandria. The fuel bundles shown in Figure A.6 are inserted end to end into the calandria's fuel channels. The pressurised light water primary coolant flows through the fuel channels, each acting as a pressure tube (10). In the PWR, the equivalent of these pressure tubes is the reactor pressure vessel. Individual pressure tubes in the CANDU may be opened independently during operation to allow on-power refuelling.

The ACR-1000 design will use pressurised light water as coolant (AECL, 2008a) and low enriched uranium as fuel. The ACR-1000 is also capable of operating with MOX fuel.

## A 4.3 Features of the ACR-1000

The ACR-1000 has a number of features, including passive designs for emergency cooling and reduced operator decision-making and action workload.

Beyond its standard CANDU safety features, the ACR-1000 design includes:

- a compact core design with improved stability and higher output;
- light water coolant, which reduces the heavy water inventory by about 60 per cent, in comparison to previous CANDU designs;
- CANFLEX-ACR fuel bundles that use low enriched uranium (LEU) fuel designed for higher burn-up and to provide negative void reactivity;
- passive safety.

A detailed comparison of the ACR-1000 design parameters and those of the Darlington and Qinshan Phase III CANDU plants is provided in Appendix B, Table B.5.

## A 4.4 Nature and quantity of discharges from the ACR-1000

(a) Liquid discharges

The predicted annual liquid discharges from the ACR-1000 are as follows (AECL, 2008b):

- predicted tritium release: 2.4E+05 GBq;
- predicted gross beta-gamma activity in liquid discharges: 2.8E+01 GBq.

(b) Gaseous discharges

The predicted annual gaseous discharges from the ACR-1000 are as follows (AECL, 2008b):

- predicted tritium release: 1.00E+05 GBq;
- predicted carbon-14 release: 5.6E+02 GBq;
- predicted iodine-131 release: 1.6E-02 GBq;
- predicted noble gases release: 3.5E+04 GBq-MeV.

It must also be noted that the predicted discharges have been provided by AECL as part of their GDA submission and have not been independently validated.

# Appendix B: Design differences

**Table B.1 Design differences – Westinghouse AP1000 and its predecessors.**

| Design Characteristics | AP1000 | Reference 2 Loop | Comments |
|---|---|---|---|
| Plant design | 60 yrs | 40 yrs | |
| Nuclear steam supply system power | 3,415 MWt | 3,410 MWt | |
| Core power | 3,400 MWt | 3,390 MWt | |
| Net electrical output | 1,000 MWe | 1,075 Mwe | |
| Reactor operating pressure | 2,250 psia | 2,250 psia | |
| Steam Generator Design pressure | 1200 psia | 1100 psia | |
| Main feedwater temp | 440 °F | 445 °F | |
| Core number of fuel assemblies | 157 | 217 | Although the AP1000 has fewer fuel assemblies, the core active fuel length is slightly greater. |
| Core active fuel length | 168 in | 150 in | |
| Fuel assembly array | 17×17 | 16×16 | |
| Number of control assemblies | 53 | 83 | |
| Number of grey rod assemblies | 16 | 8 (part length) | |
| Average linear power | 5.707 kW/ft | 5.34 kW/ft | |
| Reactor vessel ID | 159 in | 172 in | |
| Reactor vessel construction | Forged rings | Welded plate | |
| Number of safety injection nozzles | 2 | 0 | |
| Steam generator type | Vertical U-tube, Recirculation design | Vertical U-tube, Recirculation design | |
| Steam generator number | 2 | 2 | |
| Heat transfer area/SG | 123,538 ft$^2$ | 103,574 ft$^2$ | |
| Number of tubes/SG | 10,025 | 9,300 | |

Table B.1 continued overleaf

**Table B.1 continued**

| Design Characteristics | AP1000 | Reference 2 Loop | Comments |
|---|---|---|---|
| Separate startup feedwater nozzle | Yes | No | |
| Reactor coolant pump type | Sealless | Shaft seal | |
| Number of reactor coolant pumps | 4 | 4 | |
| Total volume pressuriser | 2,100 $ft^3$ | 1,500 $ft^3$ | |
| Auto depressurization | Yes | No | |
| Containment type | Steel | Steel | |
| Containment inside diameter | 130 ft | 140 ft | Smaller size of design for the AP1000. |
| Containment volume | 2.06 E+06 $ft^3$ | 2.677 E+06 $ft^3$ | |
| Containment post accident cooling | Air and water on outside of steel containment vessel | Component cooling water cooled fan coolers | |
| Safety injection accumulator- #/volume | 2/2,000 $ft^3$ | 4/2,250 $ft^3$ | |
| Refuel water storage tank | 1 | 1 | |
| Refuel water storage tank volume | 590,000 gal | 475,000 gal | |
| Normal Residual Heat Removal (NRHR) design pressure | 900 psig | 650 psig | |
| Normal RHR pumps- #/design flow | 2/1,000 gpm per pump | 2/4,050 gpm per pump | |
| Safety related cooling water system | No | Yes | |
| Component cooling water pumps | 2 | 3 | |
| Service water pumps | 2 | None | |
| Heat sink | Separate mechanical draft cooling towers | Separate mechanical draft cooling towers | |
| Type of instrumentation and control system | Digital | Analog | |
| Type of instrumentation and control room | Work station | Control boards | |
| Electrical: Diesels- # | 2 | 2 | |
| Diesels electrical capacity | 4,000kW | 4,400 kW | |

**Table B.2 Design differences – EDF/Areva EPR and its predecessors**

| Design Characteristics | EPR | Konvoi | N4 plants | Comments |
|---|---|---|---|---|
| **Overall** | | | | |
| Net electrical output | ≈ 1660 MW | 1365 MW | 1475 MW | |
| Reactor thermal power | 4500 MW | 3850 MW | 4250 MW | |
| Efficiency | ≈ 36% | 35.40% | 34.50% | |
| Plant design life | 60 years | 40 years | 40 years | |
| Number of fuel assemblies (FA) in core | 241 | 193 | 205 | The increase in EPR design power has been accommodated by an increase in the number of fuel assemblies. |
| Active core height | 420 cm | 390 cm | 427 cm | |
| Enrichment (max) | 5% of U 235 | 4% of U 235 | 4% of U 235 | |
| Batch discharge burn up | 55 to 65 MWd/kg | 50 MWd/kg | 50 MWd/kg | |
| Number and kind of control rods | 89 black rods | 61 black rods | 65 black rods and 8 grey rods | |
| Pressurizer internal volume | 75 $m^3$ | 65 $m^3$ | 60 $m^3$ | |
| Steam generator heat transfer surface area | 7960 $m^2$ (with economizer) | 5400 $m^2$ (without economizer) | 7308 $m^2$ (with economizer) | |
| Water storage tank (IRWST) arrangement | Inside containment | Annulus | Outside reactor building | |
| Medium head safety injection (MHSI) shutoff head | 85/97 bar | 110 bar | 145 bar | |
| Component cooling water system (CCWS) | 4 trains (1 pump per train, 1 heat exchanger per train) | 4 trains (2 pumps and 1 heat exchanger per train, 2 trains with emergency pump) | 2 trains (2 pumps 100% per train, 2 half exchangers per train) | |

Table B.2 continued overleaf

**Table B.2 continued**

| Design Characteristics | EPR | Konvoi | N4 plants | Comments |
|---|---|---|---|---|
| Essential service water system (ESWS) | 4 trains (1 pump per train) | 4 trains (1 pump and 1 heat exchanger per train, 2 trains with emergency pump) | 2 trains (2 pumps 100% per train) | |
| Containment functions fulfilled by: | Primary and secondary walls with an annulus between them, collection of possible leakage through the primary wall in the annulus and filtration before release to the environment via stack systems for the retention and control of leakages and leak-off system for some penetrations systems for containment isolation monitoring systems to control the pressure and temperature conditions inside containment (HVAC, heat removal from IRWST, CHRS) | Primary wall (steel sphere) collection of possible leakage through the primary wall and filtered release via stack (annulus air extraction systems) systems for the retention and control of leakages and leak-off system for some penetrations, systems for containment isolation monitoring systems to control the pressure and temperature conditions inside containment (HVAC, heat removal from the sump, filtered venting system) | Primary and secondary walls with an annulus between them, collection of possible leakage through the primary wall in the annulus and filtration before release to the environment via stack systems for the retention and control of the leakages through the peripheral buildings, systems for containment isolation monitoring systems to control the pressure and temperature conditions inside containment (HVAC, spray system, filtered venting) | |
| Protection against external hazards: Aircraft crash | Light aircraft, military aircraft, large commercial aircraft | Military aircraft | (Cessna, Learjet) | |

**Table B.3 Design Differences – EDF N4 and Its Predecessors.**

| Design Characteristics | N4 | Golfech-1 and -2 | Penly-1 and -2 | Comments |
|---|---|---|---|---|
| **Overall** | | | | |
| Net electrical output | 1,475 MW | 1363 MWe (gross) | 1,382 MWe (gross) | |
| Reactor thermal power | 4,250 MW | 3,817 MWt | 3,817 MWt | |
| Efficiency | 34.50% | | | |
| Plant design life | 40 years | | | |
| **Reactor Coolant System** | | | | |
| Number of loops | 4 | 4 | 4 | |
| **Core Design** | | | | |
| Number of fuel assemblies (FA) | 205 | 193 | 193 | |
| Number of control rods | 73 | 53 control rods plus 12 safety rods | 53 control rods plus 12 safety rods | |
| Enrichment (max) | 4 % U 235 | Initial: 2.1/2.6/3.1%<br>Reload: 3.16% | Initial: 1.5/2.4/2.9%<br>Reload: 3.16% | |
| Batch discharge burn up | 50 MWd/kg | 33 MWd/kg | 33 MWd/kg | |
| **Reactor Pressure Vessel** | | | | |
| Material | 16 MN D5 / 20 | SA 508 Cl 3 | SA 508 Cl 3 | |

Table B.3 continued overleaf

**Table B.3 continued**

| Design Characteristics | N4 | Golfech-1 and -2 | Penly-1 and -2 | Comments |
|---|---|---|---|---|
| **Containment** | | | | |
| Containment concept | Double wall containment concept with a primary wall in pre-stressed concrete without liner, 73 000 m³ free volume, a secondary wall in reinforced concrete. | Pre-stressed concrete/steel | Pre-stressed concrete/steel | |
| Design pressure for DBAs (abs) | LOCA or steam line break 0.53 MPa | 0.4021 MPa | 0.4021 MPa | |

**Table B.4 Design differences – GE-Hitachi ESBWR and its predecessors.**

| Design Characteristic | ESBWR | ABWR | BWR | Comments |
|---|---|---|---|---|
| **Overall** | | | | |
| Net electrical output | 1560 MWe | 1350 MWe | 1300 MW(e) | |
| Reactor thermal power | N/A | N/A | 3926 MWth | |
| Efficiency | 34.7% | N/A | 33.1% | |
| Plant design life | 60 years | 60 years | N/A | |
| Rate power | 4500 MWt | 3926 MWt | N/A | |
| Design power (ECCS design basis) | 4590 MWt | 4005 MWt | N/A | |
| Number of fuel bundles | 1132 | 872 | 872 | |
| Active fuel length | 3048 mm | 3708 mm | 3.810 mm | |
| Average power densities | 54.3 kW/liter | 50.6 kW/liter | 50.6kW/liter | |
| Average linear heat generation rate | 15.1 kW/m | 20.3 kW/m | N/A | |
| Average heat flux | 458.53 kW/m$^2$ | 524.86 kW/m$^2$ | 424.00 kW/m$^2$ | |
| First core initial average U$^{235}$ enrichment | 2.00% | 2.22% | ≈ 2.00% | The ESBWR design does not have the highest average enrichment of U$^{235}$ |
| Fuel assembly rod array | 10×10 | 8×8 | 10×10 square lattice | |
| Number of fuel rods per assembly | 92 | 62 | 92 | |
| Fuel rod cladding material | Zircaloy-2 | Zircaloy-2 | Zircaloy-2 | |
| Fuel assembly overall length | 379 cm | 447 cm | 447 cm | |

Table B.4 continued overleaf

**Table B.4 continued**

| Design Characteristic | ESBWR | ABWR | BWR | Comments |
|---|---|---|---|---|
| Weight of $UO_2$ per assembly | 144 kg | 197 kg | 181 kg | |
| Weight of fuel assembly (includes channel without $UO_2$) | 79 kg | 78 kg | N/A | |
| Fuel channel thickness | 3.05/1.91 mm | 2.5 mm | 0.66mm (cladding) | |
| Fuel channel cross section dimension | 140 mm | 139 mm | 106 mm | |
| Method of variation of reactor power | Control rods | Control rods and core flow | N/A | |
| Number of control rods | 269 | 205 | 205 | |
| Type of control rod drives | Bottom entry electric hydraulic fine motion | Bottom entry electric hydraulic fine motion | Electro-mechanical/hydraulic | The ESBWR design follows on closely from the ABWR control rod drives |
| Reactor vessel material | Low-alloy steel/stainless and Ni-Cr-Fe Alloy clad | Low-alloy steel/stainless and Ni-Cr-Fe Alloy clad | Low-alloy carbon steel/stainless steel | |
| Reactor vessel design gauge pressure | 8.62 MPa | 8.62 Mpa | 8.62 Mpa | |
| Reactor vessel design temperature | 302 °C | 302 °C | 301.7°C | |
| Reactor vessel inside diameter | 7061 mm | 7061 mm | 7100 mm | |
| Reactor vessel inside height | 27,560 mm | 21,056 mm | 21,000 mm | |
| Number of reactor coolant recirculation loops | Natural circulation internal to reactor vessel | Forced recirculation internal to reactor vessel | Variable speed, wet motor, single stage, vertical internal pump | |
| Number of steamlines | 4 | 4 | N/A | |
| Steamlines pipe diameter | 711 mm | 711 mm | N/A | |

Table B.4 continued overleaf

**Table B.4 continued**

| Design Characteristic | ESBWR | ABWR | BWR | Comments |
|---|---|---|---|---|
| Number of isolation condenser loops | 4 | N/A | N/A | The ESBWR Isolation Condenser System is the most comparable system to the BWR Reactor Core Isolation Cooling (RCIC) System |
| Heat transfer/loop | 33.75 MW | N/A | N/A | |
| Primary containment type | Pressure suppression | Pressure suppression | Pressure suppression | |
| Construction | Reinforced concrete with steel liner; steel structure | Reinforced concrete with steel liner; steel structure | Reinforced concrete | |
| Pressure-suppression pool water volume (at low water level) | 4383 $m^3$ | 3580 $m^3$ | N/A | |
| Containment cooling system residual heat removal (RHR), number of loops | None | 3 | N/A | The ESBWR is a passive plant and does not have the traditional RHR system. |
| Containment cooling system residual heat removal (RHR), number of pumps | N/A | 3 | N/A | The ESBWR is a passive plant and does not have the traditional RHR system. |
| Containment cooling system residual heat removal (RHR), number of heat exchangers | N/A | 3 | N/A | The ESBWR is a passive plant and does not have the traditional RHR system. |

Table B.4 continued overleaf

**Table B.4 continued**

| Design Characteristic | ESBWR | ABWR | BWR | Comments |
|---|---|---|---|---|
| Containment cooling system passive containment cooling system, number of pumps | 0 | N/A | N/A | |
| Containment cooling system passive containment cooling system (PCCS), number of heat exchangers | 6 | N/A | N/A | The Ebbw's PCCS consists of six independent closed loop extensions of the containment. Each loop contains a heat exchanger (PCCS condenser) that condenses steam on the tube side and transfers heat to water in a large pool, which is vented to atmosphere. |
| High pressure core flooder (HPCF) number of loops | None | 2 | N/A | |
| Reactor core isolation cooling (RCIC) number of loops | None | 1 | N/A | |
| Low pressure flooder (LPFL) mode of Residual Heat Removal (RHR) number of loops | None | 3 | N/A | |
| Low pressure flooder (LPFL) mode of Residual Heat Removal (RHR) number of pumps | N/A | 3 | N/A | |

Table B.4 continued overleaf

**Table B.4 continued**

| Design Characteristic | ESBWR | ABWR | BWR | Comments |
|---|---|---|---|---|
| Gravity-driven cooling system (GDCS) number of loops | 4 (Interfacing with 3 GDCS pools) | None | N/A | The ESBWR's GDCS provides flow to the annulus region of the reactor through dedicated nozzles. |
| Gravity-driven cooling system (GDCS) number of pumps | 0 | N/A | N/A | |

Notes: Parameters are relative to rated power
ESBWR fuel and core design data in this table is representative and may be modified consistent with fuel licensing acceptance criteria.
ABWR uses Reactor Internal Pumps (RIPs).
Steam flow will vary somewhat with design feedwater temperature. Value shown here is for feedwater temperature of 215.6°C.
N/A = not available

**Table B.5 Design differences – AECL ACR-1000 and its predecessors.**

| Design Characteristics | ACR-1000 | CANDU-6 | Darlington | Comments |
|---|---|---|---|---|
| Reactor core output (MWth) | 3187 | 2064 | 2657 | |
| Reactor core coolant | Pressurised light water | Pressurised $D_2O$ | Pressurised $D_2O$ | The use of light water coolant is a design simplification allowing for reduction of systems for cleanup and recovery. |
| Reactor core moderator | $D_2O$ | $D_2O$ | $D_2O$ | |
| Reactor core calandria diameter (m) | 7.5 | 7.6 | 8.5 | |
| Reactor core fuel channel | Horizontal Zr 2.5wt%Nb alloy pressure tubes with modified 403 stainless steel end-fittings | Horizontal Zr 2.5wt%Nb alloy pressure tubes with modified 403 stainless steel end-fittings | Horizontal Zr 2.5wt%Nb alloy pressure tubes with modified 403 stainless steel end-fittings | All are centred in a zircaloy calandria tube. |
| Reactor core fuel channels | 520 | 380 | 480 | The higher number of fuel channels corresponds to the reactor core output. |
| Reactor core lattice pitch (mm) | 240 | 286 | 286 | |
| Reactor core pressure tube wall thickness (mm) | 6.5 | 4 | 4 | |
| Fuel | Low enriched $UO_2$ | Natural $UO_2$ | Natural $UO_2$ | |
| Fuel burn-up (MWd/te U) | 20,000 | 7,500 | 7,791 | |
| Fuel bundle assembly | 43-element CANFLEX-ACR | 37 element | 37 element | The ACR-1000 uses the 43-element CANFLEX-ACR fuel bundle design. The centre element contains neutron absorbers, while the remaining elements contain U-235 enriched $UO_2$ pellets. |
| Bundles per fuel channel | 12 | 12 | 13 | |

Table B.5 continued overleaf

**Table B.5 continued**

| Design Characteristics | ACR-1000 | CANDU-6 | Darlington | Comments |
|---|---|---|---|---|
| Containment structure type | Pre-stressed concrete / steel liner | Pre-stressed concrete / epoxy liner | Not included | |
| Reactor building inside diameter | 56.5m | 41.4m | Not included | |
| Reactor building containment wall thickness | 1.8m | 1.07m | Not included | |
| Reactor building height (base slab to top of the dome) | 74.0m | 51.2m | Not included | |
| Reactor outlet header pressure (Mpa (g)) | 11.1 | 9.9 | 9.9 | |
| Reactor outlet header temperature (°C) | 319 | 310 | 310 | |
| Reactor inlet header pressure (Mpa (g)) | 12.5 | 11.2 | 11.3 | |
| Reactor inlet header temperature (°C) | 275 | 260 | 267 | |
| Single channel flow (maximum) (kg/s) | 28 | 28 | 27.4 | |
| Number of heat transport pumps | 4 | 4 | 4 | The ACR-1000 heat transport pumps are an enhanced, larger version of the double-discharge design used in the CANDU-6 and Darlington reactors. |
| Heat transport pump rated flow (L/s) | 4300 | 2228 | 3240 | |
| Heat transport motor rating (MWe) | 10.0 | 6.7 | 9.6 | |

Table B.5 continued overleaf

**Table B.5 continued**

| Design Characteristics | ACR-1000 | CANDU-6 | Darlington | Comments |
|---|---|---|---|---|
| Number of steam generators | 4 | 4 | 4 | The ACR-1000 steam generators are similar to the CANDU-6 and Darlington designs, except for the larger physical size. |
| Steam generators type | Vertical U-tube / integral pre-heater | Vertical U-tube / integral pre-heater | Vertical U-tube / integral pre-heater | |
| Steam generators nominal tube diameter (mm) | 17.5 (11/16'') | 15.9 (5/8'') | 15.9 (5/8'') | |
| Steam generators steam temperature (nominal) (°C) | 275.5 | 260 | 265 | |
| Steam generators steam quality | 0.999 | 0.9975 | 0.9975 | The ACR-1000's steam wetness at the steam nozzle has been reduced to 0.1% based on the latest steam separator technology, leading to improved turbine cycle economics. |
| Steam generators steam pressure (Mpa (g)) | 5.9 | 4.6 | 5.0 | |
| Heavy water moderator system (Mg$D_2O$) | 250 | 265 | 312 | The ACR-1000 moderator is a low pressure, low temperature system that is fully independent of the heat transport system. Heavy water acts as both moderator and reflector for the neuron flux in the core |
| Heavy water heat transport system (Mg$D_2O$) | 0 | 192 | 280 | |
| Total (Mg$D_2O$) | 250 | 457 | 592 | |

Table B.5 continued overleaf

**Table B.5 continued**

| Design Characteristics | ACR-1000 | CANDU-6 | Darlington | Comments |
|---|---|---|---|---|
| Steam turbine type | Impulse-type tandem-compound | Hitachi impulse-type, tandem-compound | Tandem-compound | |
| Steam turbine composition | One double-flow high pressure cylinder | One double-flow high pressure cylinder | One double-flow high pressure cylinder | |
| Net to turbine (MWth) | 3180 | 2060 | 2650 | |
| Gross/Net electrical output* (nominal) (MWe) | 1165/1085 | 728/666 | 935/881 | |
| Turbine generator efficiency** | ≈ 36.6% | 35.3% | 35.3% | |
| Steam temperature at main stop valve (°C) | 273 | 258 | 263 | |
| Final feedwater temperature (°C) | 217 | 187 | 177 | |
| Condenser vacuum (kPa (a)) | 4.9 | 4.9 | 4.2 | |

Notes: CANDU-6 data quoted is based on the Qinshan Phase III CANDU-6 design.
Approximate values: electrical output is dependent on site conditions.
Motor-driven feedwater pump, CANDU-6 and ACR-1000 outputs are based on reference cooling water temperature of 18.8°C.
Darlington output is based in reference cooling water temperature of 11°C.

# Appendix C: Summary of abatement technologies

**Table C.1 Summary of abatement technologies.**

| Waste stream | ACR-1000 | ESBWR | EPR | AP1000 |
|---|---|---|---|---|
| **Abatement technology** | | | | |
| Liquid waste | Liquid radioactive waste is treated using cartridge filters and ion-exchange resins. | Liquid radioactive waste is treated using reverse osmosis and ion-exchangers. | The EPR proposes to reduce its generation of tritium through reducing boron concentrations and changing lithium hydroxide concentrations.<br>The EPR design will not incorporate any specific plant for the abatement of C-14 discharges in liquid. | The liquid radwaste system of the AP1000 provides the capability to reduce the amounts of radioactive nuclides released in the liquid wastes through the use of demineralisation and time delay for decay of short-lived nuclides. |
| Tritiated water vapour | A vapour recovery system is used to abate discharge of tritium to the atmosphere. The system collects and condenses vapour using desiccant dehumidifiers or an equivalent vapour condensing technology. | Abatement of release of radioactive gases by:<br>- Use of drywell purge system (charcoal filtration system)<br>- Maintain steam dryer and separator surfaces wet or covered.<br>- Cool fuel pools through large heat capacity heat exchangers.<br>- Fuel pool ventilation system designed to sweep the pool surface and prevent pool releases from mixing with the area atmosphere. | The EPR will use containment within plant and recycling where possible. The EPR also proposes treatment to ensure that most hazardous isotopes are removed in effluent streams and contained within solid filters. Hold up to allow decay of short-lived species and finally monitoring and discharge via a stack designed to ensure maximum rapid dispersion and dilution in the air. | |

Table C.1 continued overleaf

**Table C.1 continued**

| **Waste stream** | **ACR-1000** | **ESBWR** | **EPR** | **AP1000** |
|---|---|---|---|---|
| Carbon-14 | Due to small amounts of C-14, no treatment system is in place to abate the discharge of C-14 to the atmosphere. | | The EPR design incorporates no new features for abatement of C-14 discharges. | The gaseous radwaste system includes a guard bed and delay beds. The guard bed consists of activated carbon and protects the delay beds from abnormal moisture or chemical contaminants. Under normal operating conditions, the guard bed provides increased delay time for xenon and krypton and removes iodine entering the system. |
| Radioactive noble gases | Radioactive noble gases can be handled by an Off-Gas Management System (OGMS) and eventually exhausted through the main stack via an Active Ventilation System (AVS). An OGMS can treat and achieve activity reduction of noble gases by typically delaying the collected gases in an absorber to allow for a period of radioactive decay. | | Containment within plant and recycling where possible. The EPR also proposes treatment to ensure that most hazardous isotopes are removed in effluent streams and contained within solid filters. Hold up to allow decay of short-lived species and finally monitoring and discharge via a stack designed to ensure maximum rapid dispersion and dilution in the air. All the ventilation systems for the BAN (Nuclear Auxiliary Building), BAS (Safety Auxiliary Building), and BK (Fuel Building) rooms can be routed to iodine Traps prior to discharge. In addition, in the EPR design, all the rooms with special cells pass through HEPA filters that can be routed to the iodine traps. | |

Table C.1 continued overleaf

**Table C.1 continued**

| Waste stream | ACR-1000 | ESBWR | EPR | AP1000 |
|---|---|---|---|---|
| Radioiodine | The discharge of radioiodine is abated using charcoal filtration for eventual solid waste disposal. | | | |
| Radioactive airborne particulates | These are captured using High Efficiency Particulate Air (HEPA) filters that are then treated as solid waste. | | | |
| Mixed gaseous emissions | Radioactive and toxic levels of mixed gaseous waste are anticipated to be low and below the jurisdictional discharge limits, and therefore would likely be discharged to atmosphere. | | | |
| Hazardous non-radiological airborne contaminants | Treated appropriately using conventional methods | | | |

# Appendix D: Discharge data for AP1000 predecessors

## Table D.1 Liquid tritium discharges for AP1000 predecessors.

**Raw Data – GBq**

| **Candidate Reactor** | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaver Valley | 1.82E+04 | 1.79E+04 | 1.72E+04 | 2.05E+04 | 1.36E+04 | 1.92E+04 | **7.29E+04** | 2.01E+04 | | | | | | | | | |
| Byron | 3.69E+04 | 5.29E+04 | 5.85E+04 | 7.62E+04 | | 5.00E+04 | 5.21E+04 | | | | 4.28E+04 | | 7.32E+04 | 8.62E+04 | **1.19E+11** | | |
| Comanche Peak | 6.92E+03 | 1.70E+04 | 2.26E+04 | 1.86E+04 | 3.29E+04 | 3.11E+04 | 3.65E+04 | 5.38E+04 | | | 4.52E+04 | 3.45E+04 | 5.12E+04 | 5.28E+04 | 3.99E+04 | | |
| Seabrook | 4.18E+03 | 1.43E+04 | 1.85E+04 | 2.08E+04 | | | | | | | | | | | | | |
| Sizewell B | | | | | | | 3.76E+04 | 4.42E+04 | 4.83E+04 | 5.57E+04 | 5.31E+04 | 6.41E+04 | 6.51E+04 | 6.89E+04 | 1.76E+04 | 3.09E+04 | 5.51E+04 |
| Takahama | 3.50E+04 | 3.00E+04 | 5.50E+04 | 6.90E+04 | 3.30E+04 | 3.70E+04 | 5.70E+04 | 6.40E+04 | 6.20E+04 | 7.10E+04 | 4.10E+04 | 5.30E+04 | 6.30E+04 | 5.90E+04 | 6.30E+04 | 6.90E+04 | 6.80E+04 |

| | |
|---|---|
| Mean | 4.30E+04 |
| Standard Deviation | 2.01E+04 |
| Maximum | 6.31E+04 |
| Minimum | 2.30E+04 |
| Prediction | 7.47E+04 |

**Normalised Data (Electrical) – GBq/GWeh**

| **Candidate Reactor** | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaver Valley | 1.74E+00 | 1.71E+00 | 1.44E+00 | 2.14E+00 | 1.09E+00 | 1.67E+00 | **6.95E+00** | 1.97E+00 | | | | | | | | | |
| Byron | 2.84E+00 | 3.51E+00 | 3.66E+00 | 5.08E+00 | | 3.15E+00 | 3.54E+00 | | | | 2.22E+00 | | 3.78E+00 | 4.28E+00 | **5.95E+06** | | |
| Comanche Peak | 2.07E+00 | 3.17E+00 | 3.26E+00 | 1.65E+00 | 2.25E+00 | 1.83E+00 | 2.41E+00 | 3.07E+00 | | | 2.45E+00 | 1.88E+00 | 3.09E+00 | 2.97E+00 | 2.10E+00 | | |
| Seabrook | 1.02E+00 | 2.10E+00 | 2.35E+00 | 2.30E+00 | | | | | | | | | | | | | |
| Sizewell B | | | | | | | 4.43E+00 | 5.22E+00 | 4.77E+00 | 7.00E+00 | 6.23E+00 | 6.97E+00 | 7.08E+00 | 7.78E+00 | 1.89E+00 | 3.55E+00 | 6.19E+00 |
| Takahama | 1.76E+00 | 1.60E+00 | 2.54E+00 | 3.13E+00 | 1.61E+00 | 1.65E+00 | 2.69E+00 | 2.78E+00 | 2.37E+00 | 2.95E+00 | 1.65E+00 | 2.08E+00 | 2.54E+00 | 2.31E+00 | 2.68E+00 | 2.78E+00 | 2.80E+00 |

| | |
|---|---|
| Mean | 3.03E+00 |
| Standard Deviation | 1.58E+00 |
| Maximum | 4.61E+00 |
| Minimum | 1.45E+00 |
| Prediction | 3.82E+00 |

**Normalised Data (Thermal) – GBq/GWth**

| **Candidate Reactor** | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaver Valley | 5.39E-01 | 5.29E-01 | 4.46E-01 | 6.63E-01 | 3.36E-01 | 5.17E-01 | **2.15E+00** | 6.11E-01 | | | | | | | | | |
| Byron | 9.19E-01 | 1.14E+00 | 1.19E+00 | 1.65E+00 | | 1.02E+00 | 1.15E+00 | | | | 7.19E-01 | | 1.22E+00 | 1.39E+00 | **1.93E+06** | | |
| Comanche Peak | 7.00E-01 | 9.82E-01 | 1.01E+00 | 5.11E-01 | 6.97E-01 | 5.68E-01 | 7.47E-01 | 9.50E-01 | | | 7.58E-01 | 5.83E-01 | 9.57E-01 | 9.21E-01 | 6.49E-01 | | |
| Seabrook | 3.48E-01 | 7.14E-01 | 8.01E-01 | 7.83E-01 | | | | | | | | | | | | | |
| Sizewell B | | | | | | | 1.54E+00 | 1.82E+00 | 1.66E+00 | 2.44E+00 | 2.17E+00 | 2.43E+00 | 2.47E+00 | 2.71E+00 | 6.57E-01 | 1.24E+00 | 2.15E+00 |
| Takahama | 5.72E-01 | 5.22E-01 | 8.29E-01 | 1.02E+00 | 5.24E-01 | 5.39E-01 | 8.76E-01 | 9.05E-01 | 7.73E-01 | 9.63E-01 | 5.38E-01 | 6.79E-01 | 8.29E-01 | 7.52E-01 | 8.74E-01 | 9.05E-01 | 9.12E-01 |

| | |
|---|---|
| Mean | 1.00E+00 |
| Standard Deviation | 5.62E-01 |
| Maximum | 1.56E+00 |
| Minimum | 4.38E-01 |
| Prediction | 1.25E+00 |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EC Report (EU, 1995-2003) |
| ▨ | RIFE Reports (RIFE, 1995-2006) |

Data marked in red, has been excluded from the mean and standard deviation calculations

## Table D.2 Other liquid discharges for AP1000 predecessors.

| **Candidate Reactor** | **Raw Data – GBq** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Beaver Valley | 9.41E+01 | 1.16E+01 | 1.26E+01 | 1.47E+01 | 7.62E+00 | 1.48E+01 | 4.14E+01 | 1.37E+01 | | 1.07E+01 | 1.32E+01 | 1.07E+01 | 5.45E+00 | 1.06E+02 | 4.68E+00 | | |
| Byron | 4.37E+01 | 2.48E+01 | 1.52E+02 | 4.66E+01 | | 6.68E+01 | | | | | **4.28E+04** | **4.46E+04** | 1.73E+01 | 3.17E+00 | 3.23E+00 | | |
| Comanche Peak | 4.40E-01 | 1.80E+00 | 1.48E+01 | 1.55E+01 | 9.20E+00 | 4.60E+00 | 5.50E+00 | 4.20E+01 | | | 4.76E+00 | 1.44E+01 | 9.28E+01 | 4.35E+00 | 6.84E-01 | | |
| Seabrook | 8.20E-02 | 4.51E+00 | 4.40E+00 | 3.40E+00 | | | | | | | | 5.08E+00 | 1.89E+00 | 4.11E+01 | 1.39E+00 | | |
| Sizewell B | | | | | | | 1.99E+01 | 2.13E+01 | 1.78E+01 | 4.58E+01 | 6.04E+01 | 5.29E+01 | 5.00E+01 | 4.42E+01 | 2.03E+01 | 2.84E+01 | 2.17E+01 |
| Takahama | | | | | | | | | | | | | | | 3.10E-04 | | |
| Mean | 2.50E+01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 3.05E+01 | | | | | | | | | | | | | | | | |
| Maximum | 5.55E+01 | | | | | | | | | | | | | | | | |
| Minimum | -5.55E+00 | | | | | | | | | | | | | | | | |
| Prediction | 2.50E+01 | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Electrical) – GBq/GWeh** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Beaver Valley | 9.00E-03 | 1.11E-03 | 1.05E-03 | 1.54E-03 | 6.08E-04 | 1.29E-03 | 3.95E-03 | 1.35E-03 | | 9.02E-04 | 1.09E-03 | 8.12E-04 | 4.01E-04 | 8.40E-03 | 3.34E-04 | | |
| Byron | 3.36E-03 | 1.64E-03 | 9.51E-03 | 3.11E-03 | | 4.20E-03 | | | | | **2.22E+00** | **2.21E+00** | 8.93E-04 | 1.57E-04 | 1.61E-04 | | |
| Comanche Peak | 1.32E-04 | 3.36E-04 | 2.13E-03 | 1.37E-03 | 6.29E-04 | 2.71E-04 | 3.64E-04 | 2.39E-03 | | | 2.57E-04 | 7.84E-04 | 5.60E-03 | 2.45E-04 | 3.59E-05 | | |
| Seabrook | 2.00E-05 | 6.62E-04 | 5.59E-04 | 3.76E-04 | | | | | | | | 5.84E-04 | 2.03E-04 | 4.43E-03 | 1.37E-04 | | |
| Sizewell B | | | | | | | 2.34E-03 | 2.51E-03 | 1.76E-03 | 5.75E-03 | 7.08E-03 | 5.75E-03 | 5.44E-03 | 4.99E-03 | 2.18E-03 | 3.27E-03 | 2.44E-03 |
| Takahama | | | | | | | | | | | | | | | 1.32E-08 | | |
| Mean | 2.18E-03 | | | | | | | | | | | | | | | | |
| Standard Deviation | 2.44E-03 | | | | | | | | | | | | | | | | |
| Maximum | 4.62E-03 | | | | | | | | | | | | | | | | |
| Minimum | -2.65E-04 | | | | | | | | | | | | | | | | |
| Prediction | 9.69E-04 | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Thermal) – GBq/GWth** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Beaver Valley | 2.79E-03 | 3.43E-04 | 3.27E-04 | 4.76E-04 | 1.88E-04 | 3.99E-04 | 1.22E-03 | 4.17E-04 | | 2.79E-04 | 3.38E-04 | 2.51E-04 | 1.24E-04 | 2.60E-03 | 1.04E-04 | | |
| Byron | 1.09E-03 | 5.32E-04 | 3.08E-04 | 1.01E-03 | | 1.36E-03 | | | | | **7.19E-01** | **7.15E-01** | 2.89E-04 | 5.09E-05 | 5.23E-05 | | |
| Comanche Peak | 4.45E-05 | 1.04E-04 | 6.61E-04 | 4.26E-04 | 1.95E-04 | 8.40E-05 | 1.13E-04 | 7.42E-04 | | | 7.97E-05 | 2.43E-04 | 1.73E-03 | 7.59E-05 | 1.11E-05 | | |
| Seabrook | 6.82E-06 | 2.25E-04 | 1.90E-04 | 1.28E-04 | | | | | | | | 1.99E-04 | 6.92E-05 | 1.51E-03 | 4.66E-05 | | |
| Sizewell B | | | | | | | 8.17E-04 | 8.76E-04 | 6.12E-04 | 2.00E-03 | 2.47E-03 | 2.00E-03 | 1.89E-03 | 1.74E-03 | 7.58E-04 | 1.14E-03 | 8.48E-04 |
| Takahama | | | | | | | | | | | | | | | 4.30E-09 | | |
| Mean | 7.16E-04 | | | | | | | | | | | | | | | | |
| Standard Deviation | 8.02E-04 | | | | | | | | | | | | | | | | |
| Maximum | 1.52E-03 | | | | | | | | | | | | | | | | |
| Minimum | -8.64E-05 | | | | | | | | | | | | | | | | |
| Prediction | 7.16E-04 | | | | | | | | | | | | | | | | |

| **Colour Code** | **Information source** |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EC Report (EU, 1995-2003) |
| ▨ | RIFE Reports (RIFE, 1995-2006) |

Data marked in red, has been excluded from the mean and standard deviation calculations

# Table D.3 Airborne tritium discharges for AP1000 predecessors.

| Candidate Reactor | Raw Data – GBq | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Beaver Valley | 3.24E+03 | 4.96E+03 | 8.03E+03 | 1.28E+04 | 1.24E+04 | 1.28E+04 | 1.31E+04 | 9.07E+03 | | | | | | | | | |
| Byron | 3.96E+01 | 3.33E+01 | 1.14E+02 | 3.40E+01 | | 1.58E+02 | 1.38E+03 | | | | | | 1.83E+02 | 1.46E+02 | 1.00E+02 | | |
| Comanche Peak | 2.25E+02 | 8.62E+01 | 1.12E+02 | 2.22E+02 | 3.16E+02 | 8.57E+02 | 1.63E+03 | 2.16E+03 | | | 1.10E+03 | 1.40E+03 | 2.11E+03 | 1.81E+03 | 1.49E+03 | | |
| Seabrook | 9.32E+00 | 5.07E+02 | 5.81E+01 | 2.34E+01 | | | | | | | | | | | | | |
| Sizewell B | | | | | | | 5.79E+02 | 5.65E+02 | 1.39E+03 | 6.86E+02 | 5.72E+02 | 1.82E+03 | 8.58E+02 | 8.82E+02 | 6.51E+02 | 7.60E+02 | 1.23E+03 |
| Takahama | 2.60E+03 | 2.90E+03 | 4.60E+03 | 5.20E+03 | 5.40E+03 | 5.90E+03 | 8.20E+03 | 8.40E+03 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 2.75E+03 | | | | | | | | | | | | | | | | |
| Standard Deviation | 3.75E+03 | | | | | | | | | | | | | | | | |
| Maximum | 6.51E+03 | | | | | | | | | | | | | | | | |
| Minimum | -1.00E+03 | | | | | | | | | | | | | | | | |
| Prediction | 2.59E+04 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Electrical) – GBq/GWeh | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Beaver Valley | 3.10E-01 | 4.74E-01 | 6.72E-01 | 1.34E+00 | 9.90E-01 | 1.11E+00 | 1.25E+00 | 8.91E-01 | | | | | | | | | |
| Byron | 3.05E-03 | 2.21E-03 | 7.13E-03 | 2.27E-03 | | 9.94E-03 | 9.39E-02 | | | | | | 9.45E-03 | 7.24E-03 | 5.00E-03 | | |
| Comanche Peak | 6.75E-02 | 1.61E-02 | 1.61E-02 | 1.97E-02 | 2.16E-02 | 5.05E-02 | 1.07E-01 | 1.23E-01 | | | 5.92E-02 | 7.63E-02 | 1.28E-01 | 1.02E-01 | 7.84E-02 | | |
| Seabrook | 2.28E-03 | 7.44E-02 | 7.38E-03 | 2.59E-03 | | | | | | | | | | | | | |
| Sizewell B | | | | | | | 6.82E-02 | 6.67E-02 | 1.37E-01 | 8.62E-02 | 6.71E-02 | 1.98E-01 | 9.33E-02 | 9.96E-02 | 6.98E-02 | 8.74E-02 | 1.38E-01 |
| Takahama | 1.30E-01 | 1.55E-01 | 2.13E-01 | 2.36E-01 | 2.63E-01 | 2.64E-01 | 3.87E-01 | 3.64E-01 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 2.12E-01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 3.26E-01 | | | | | | | | | | | | | | | | |
| Maximum | 5.38E-01 | | | | | | | | | | | | | | | | |
| Minimum | -1.14E-01 | | | | | | | | | | | | | | | | |
| Prediction | 1.32E+00 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Thermal) – GBq/GWth | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Beaver Valley | 9.60E-02 | 1.47E-01 | 2.08E-01 | 4.14E-01 | 3.07E-01 | 3.45E-01 | 3.87E-01 | 2.76E-01 | | | | | | | | | |
| Byron | 9.86E-04 | 7.15E-04 | 2.31E-03 | 7.35E-04 | | 3.22E-03 | 3.04E-02 | | | | | | 3.06E-03 | 2.35E-03 | 1.62E-03 | | |
| Comanche Peak | 2.27E-02 | 4.98E-03 | 5.00E-03 | 6.10E-03 | 6.69E-03 | 1.56E-02 | 3.33E-02 | 3.81E-02 | | | 1.83E-02 | 2.36E-02 | 3.95E-02 | 3.17E-02 | 2.43E-02 | | |
| Seabrook | 7.76E-04 | 2.53E-02 | 2.52E-03 | 8.81E-04 | | | | | | | | | | | | | |
| Sizewell B | | | | | | | 2.38E-02 | 2.32E-02 | 4.78E-02 | 3.00E-02 | 2.34E-02 | 6.89E-02 | 3.25E-02 | 3.47E-02 | 2.43E-02 | 3.04E-02 | 4.81E-02 |
| Takahama | 4.25E-02 | 5.04E-02 | 6.93E-02 | 7.68E-02 | 8.58E-02 | 8.60E-02 | 1.26E-01 | 1.19E-01 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 6.73E-02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.01E-01 | | | | | | | | | | | | | | | | |
| Maximum | 1.68E-01 | | | | | | | | | | | | | | | | |
| Minimum | -3.36E-02 | | | | | | | | | | | | | | | | |
| Prediction | 4.33E-01 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ▨ | RIFE Reports (RIFE, 1995-2006) |

# Table D.4 Airborne noble gas discharges for AP1000 predecessors.

**Candidate Reactor** — **Raw Data – GBq**

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaver Valley | 3.02E+03 | 5.51E+03 | 5.74E+03 | 2.06E+04 | 7.62E+03 | 5.81E+03 | 1.05E+04 | 5.66E+03 | | 2.62E+03 | 4.42E+03 | 2.28E+02 | 9.51E+02 | 2.27E+03 | 2.87E+02 | | |
| Byron | **4.59E+04** | 3.85E+03 | 1.39E+04 | 4.51E+03 | | 4.26E+03 | 1.01E+03 | | | | 6.75E+01 | 6.49E+01 | 8.29E+01 | 4.54E+02 | 5.99E+02 | | |
| Comanche Peak | **3.35E+04** | **2.18E+05** | **6.51E+04** | 7.10E+03 | 8.10E+01 | 1.05E+03 | 9.32E+02 | 9.50E+01 | | | 3.87E+01 | 4.88E+01 | 8.44E+03 | 1.29E+02 | 2.08E+02 | | |
| Seabrook | 3.96E+03 | 1.08E+03 | 3.38E+01 | 4.00E+00 | | | | | | | | 1.16E+03 | 1.36E+03 | 2.69E+01 | 1.54E+00 | | |
| Sizewell B | | | | | | | 6.11E+03 | 4.36E+03 | 1.57E+04 | 7.29E+03 | 1.25E+04 | 4.93E+03 | 5.14E+03 | 4.30E+03 | 3.08E+03 | 3.43E+03 | 3.05E+03 |
| Takahama | 3.50E+02 | 1.80E+03 | 4.40E+02 | 6.20E+02 | 2.00E+02 | 2.10E+02 | 3.30E+02 | 3.70E+02 | 4.20E+02 | 4.00E+02 | 1.60E+01 | 1.80E+01 | 1.20E+01 | 1.10E+01 | 1.60E+01 | 1.20E+01 | 1.50E+01 |
| | | | | | | | | | | | | | | | | | |
| Mean | 2.93E+03 | | | | | | | | | | | | | | | | |
| Standard Deviation | 4.12E+03 | | | | | | | | | | | | | | | | |
| Maximum | 7.05E+03 | | | | | | | | | | | | | | | | |
| Minimum | -1.19E+03 | | | | | | | | | | | | | | | | |
| Prediction | 8.17E+05 | | | | | | | | | | | | | | | | |

**Candidate Reactor** — **Normalised Data (Electrical) – GBq/GWeh**

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaver Valley | 2.89E-01 | 5.26E-01 | 4.81E-01 | 2.15E+00 | 6.08E-01 | 5.05E-01 | 1.00E+00 | 5.56E-01 | | 2.21E-01 | 3.65E-01 | 1.73E-02 | 7.00E-02 | 1.80E-01 | 2.05E-02 | | |
| Byron | **3.53E+00** | 2.55E-01 | 8.69E-01 | 3.01E-01 | | 2.68E-01 | 6.87E-02 | | | | 3.50E-03 | 3.21E-03 | 4.28E-03 | 2.25E-02 | 2.99E-02 | | |
| Comanche Peak | **1.00E+01** | **4.07E+01** | **9.38E+00** | 6.29E-01 | 5.54E-03 | 6.16E-02 | 6.16E-02 | 5.42E-03 | | | 2.09E-03 | 2.66E-03 | 5.09E-01 | 7.26E-03 | 1.09E-02 | | |
| Seabrook | 9.67E-01 | 1.58E-01 | 4.30E-03 | 4.42E-04 | | | | | | | | 1.34E-01 | 1.46E-01 | 2.90E-03 | 1.51E-04 | | |
| Sizewell B | | | | | | | 7.20E-01 | 5.15E-01 | 1.55E+00 | 9.16E-01 | 1.47E+00 | 5.36E-01 | 5.59E-01 | 4.86E-01 | 3.30E-01 | 3.94E-01 | |
| Takahama | 1.76E-02 | 9.60E-02 | 2.03E-02 | 2.81E-02 | 9.75E-03 | 9.39E-03 | 1.56E-02 | 1.61E-02 | 1.61E-02 | 1.66E-02 | 6.44E-04 | 7.08E-04 | 4.85E-04 | 4.30E-04 | 6.81E-04 | 4.83E-04 | |
| | | | | | | | | | | | | | | | | | |
| Mean | 2.80E-01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 4.16E-01 | | | | | | | | | | | | | | | | |
| Maximum | 6.96E-01 | | | | | | | | | | | | | | | | |
| Minimum | -1.36E-01 | | | | | | | | | | | | | | | | |
| Prediction | 4.17E+01 | | | | | | | | | | | | | | | | |

**Candidate Reactor** — **Normalised Data (Thermal) – GBq/GWth**

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaver Valley | 8.94E-02 | 1.63E-01 | 1.49E-01 | 6.67E-01 | 1.88E-01 | 1.57E-01 | 3.10E-01 | 1.72E-01 | | 6.84E-02 | 1.13E-01 | 5.36E-03 | 2.17E-02 | 5.57E-02 | 6.35E-03 | | |
| Byron | **1.14E+00** | 8.26E-02 | 2.82E-01 | 9.75E-02 | | 8.68E-02 | 2.23E-02 | | | | 1.13E-03 | 1.04E-03 | 1.39E-03 | 7.30E-03 | 9.70E-03 | | |
| Comanche Peak | **3.39E+00** | **1.26E+01** | **2.91E+00** | 1.95E-01 | 1.71E-03 | 1.91E-02 | 1.91E-02 | 1.68E-03 | | | 6.48E-04 | 8.24E-04 | 1.58E-01 | 2.25E-03 | 3.38E-03 | | |
| Seabrook | 3.30E-01 | 5.40E-02 | 1.46E-03 | 1.51E-04 | | | | | | | | 4.56E-02 | 4.97E-02 | 9.87E-04 | 5.14E-05 | | |
| Sizewell B | | | | | | | 2.51E-01 | 1.79E-01 | 5.40E-01 | 3.19E-01 | 5.11E-01 | 1.87E-01 | 1.95E-01 | 1.69E-01 | 1.15E-01 | 1.37E-01 | 1.19E-01 |
| Takahama | 5.72E-03 | 3.13E-02 | 6.63E-03 | 9.15E-03 | 3.18E-03 | 3.06E-03 | 5.07E-03 | 5.23E-03 | 5.23E-03 | 5.43E-03 | 2.10E-04 | 2.31E-04 | 1.58E-04 | 1.40E-04 | 2.22E-04 | 1.57E-04 | 2.01E-04 |
| | | | | | | | | | | | | | | | | | |
| Mean | 9.20E-02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.37E-01 | | | | | | | | | | | | | | | | |
| Maximum | 2.29E-01 | | | | | | | | | | | | | | | | |
| Minimum | -4.50E-02 | | | | | | | | | | | | | | | | |
| Prediction | 1.36E+01 | | | | | | | | | | | | | | | | |

| **Colour Code** | **Information source** |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ▨ | RIFE Reports (RIFE, 1995-2006) |

Data marked in red, has been excluded from the mean and standard deviation calculations

## Table D.5 Airborne iodine-131 discharges for AP1000 predecessors.

**Raw Data – GBq**

| **Candidate Reactor** | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaver Valley | 5.10E-03 | 2.60E-01 | 2.80E-02 | 2.50E-01 | 1.40E-02 | 9.10E-02 | 4.70E-01 | 4.10E-02 |  | 6.29E-03 | 5.23E-02 | 2.30E-03 | 1.35E-02 | **6.00E+01** | 1.34E-02 |  |  |
| Byron | 1.50E-01 | 6.30E-03 | 1.60E-02 | 1.60E-02 |  | 2.40E-02 | 1.70E-02 |  |  |  | 5.70E-05 |  | 1.14E-03 | 1.90E-04 | 6.14E-03 |  |  |
| Comanche Peak |  | 7.00E-04 | 3.10E-02 | 3.70E-03 |  |  | 5.00E-05 |  |  |  |  |  | 5.88E-03 |  |  |  |  |
| Seabrook |  | 7.00E-04 | 1.00E-04 |  |  |  |  |  |  |  |  | 6.11E-05 | 1.41E-02 | 7.63E-03 |  |  |  |
| Sizewell B |  |  |  |  |  |  | 4.92E-02 | 3.42E-02 | 5.95E-02 | 3.35E-01 | 2.47E+00 | 9.28E-02 | 1.89E-01 | 1.19E+00 | 1.20E-01 | 1.54E-03 | 5.33E-01 |
| Takahama | 3.00E-04 | 2.20E-01 | 4.30E-02 | 4.00E-04 | 3.00E-04 | 2.00E-04 |  | 3.80E-03 | 9.90E-03 | 2.70E-04 |  | 1.80E-04 | 3.40E-04 |  |  |  |  |
| Mean | 1.25E-01 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Standard Deviation | 3.74E-01 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Maximum | 4.99E-01 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Minimum | -2.49E-01 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Prediction | 8.88E+00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**Normalised Data (Electrical) – GBq/GWeh**

| **Candidate Reactor** | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaver Valley | 4.88E-07 | 2.48E-05 | 2.34E-06 | 2.61E-05 | 1.12E-06 | 7.92E-06 | 4.48E-05 | 4.03E-06 |  | 5.30E-07 | 4.32E-06 | 1.74E-07 | 9.93E-07 | **4.75E-03** | 9.58E-07 |  |  |
| Byron | 1.15E-05 | 4.17E-07 | 1.00E-06 | 1.07E-06 |  | 1.51E-06 | 1.16E-06 |  |  |  | 2.95E-09 |  | 5.89E-08 | 9.43E-09 | 3.07E-07 |  |  |
| Comanche Peak |  | 1.31E-07 | 4.47E-06 | 3.28E-07 |  |  | 3.31E-09 |  |  |  |  |  | 3.55E-07 |  |  |  |  |
| Seabrook |  | 1.03E-07 | 1.27E-08 |  |  |  |  |  |  |  |  | 7.02E-09 | 1.52E-06 | 8.23E-07 |  |  |  |
| Sizewell B |  |  |  |  |  |  | 5.80E-06 | 4.04E-06 | 5.88E-06 | 4.21E-05 | 2.90E-04 | 1.01E-05 | 2.06E-05 | 1.34E-04 | 1.29E-05 | 1.77E-07 | 5.98E-05 |
| Takahama | 1.50E-08 | 1.17E-05 | 1.99E-06 | 1.81E-08 | 1.46E-08 | 8.95E-09 |  | 1.65E-07 | 3.79E-07 | 1.12E-08 |  | 7.08E-09 | 1.37E-08 |  |  |  |  |
| Mean | 1.35E-05 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Standard Deviation | 4.34E-05 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Maximum | 5.69E-05 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Minimum | -2.99E-05 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Prediction | 4.54E-04 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**Normalised Data (Thermal) – GBq/GWth**

| **Candidate Reactor** | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaver Valley | 1.51E-07 | 7.69E-06 | 7.26E-07 | 8.09E-06 | 3.46E-07 | 2.45E-06 | 1.39E-05 | 1.25E-06 |  | 1.64E-07 | 1.34E-06 | 5.40E-08 | 3.08E-07 | **1.47E-03** | 2.97E-07 |  |  |
| Byron | 3.74E-06 | 1.35E-07 | 3.24E-07 | 3.46E-07 |  | 4.89E-07 | 3.75E-07 |  |  |  | 9.57E-10 |  | 1.91E-08 | 3.05E-09 | 9.94E-08 |  |  |
| Comanche Peak |  | 4.05E-08 | 1.38E-06 | 1.02E-07 |  |  | 1.02E-09 |  |  |  |  |  | 1.10E-07 |  |  |  |  |
| Seabrook |  | 3.50E-08 | 4.33E-09 |  |  |  |  |  |  |  |  | 2.39E-09 | 5.18E-07 | 2.80E-07 |  |  |  |
| Sizewell B |  |  |  |  |  |  | 2.02E-06 | 1.41E-06 | 2.05E-06 | 1.47E-05 | 1.01E-04 | 3.51E-06 | 7.16E-06 | 4.68E-05 | 4.48E-06 | 6.17E-08 | 2.08E-05 |
| Takahama | 4.90E-09 | 3.83E-06 | 6.48E-07 | 5.91E-09 | 4.77E-09 | 2.92E-09 |  | 5.37E-08 | 1.23E-07 | 3.66E-09 |  | 2.31E-09 | 4.47E-09 |  |  |  |  |
| Mean | 4.61E-06 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Standard Deviation | 1.51E-05 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Maximum | 1.97E-05 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Minimum | -1.05E-05 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Prediction | 1.48E-04 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ▒ | RIFE Reports (RIFE, 1995-2006) |

Data marked in red, has been excluded from the mean and standard deviation calculations

## Table D.6 Airborne particulate discharges for AP1000 predecessors.

**Candidate Reactor** — **Raw Data – GBq**

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaver Valley | 1.90E-02 | 1.10E-01 | 2.90E-02 | **5.60E-01** | 4.50E-02 | **7.30E-01** | 4.80E-02 | 2.90E-02 | | 3.33E-01 | 2.17E-02 | 1.20E-02 | 2.84E-01 | 9.63E-02 | 1.68E-03 | | |
| Byron | 1.50E-03 | 4.00E-04 | | 2.20E-04 | | 8.60E-04 | 3.90E-03 | | | | 1.93E-04 | 3.58E-04 | 1.22E-04 | 2.99E-04 | 1.62E-04 | | |
| Comanche Peak | 1.40E-03 | | | 1.40E-04 | | | 8.00E-05 | | | | | | | | | | |
| Seabrook | | 3.90E-02 | 4.10E-02 | 2.00E-05 | | | | | | | | 4.67E-04 | 3.53E-04 | 1.44E-02 | 1.65E-03 | | |
| Sizewell B | | | | | | | 8.71E-03 | 4.95E-03 | 1.06E-02 | 3.54E-03 | 1.81E-02 | 7.34E-03 | 7.14E-03 | 1.15E-02 | 3.86E-03 | 3.76E-02 | 4.52E-02 |
| Takahama | | | | | | | | | | | | | | | | | |

| | |
|---|---|
| Mean | 3.01E-02 |
| Standard Deviation | 6.70E-02 |
| Maximum | 9.71E-02 |
| Minimum | -3.69E-02 |
| Prediction | 3.50E+00 |

**Candidate Reactor** — **Normalised Data (Electrical) – GBq/GWeh**

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaver Valley | 1.82E-06 | 1.05E-05 | 2.43E-06 | **5.85E-05** | 3.59E-06 | **6.35E-05** | 4.58E-06 | 2.85E-06 | | 2.81E-05 | 1.79E-06 | 9.10E-07 | 2.09E-05 | 7.63E-06 | 1.20E-07 | | |
| Byron | 1.15E-07 | 2.65E-08 | | 1.47E-08 | | 5.41E-08 | 2.65E-07 | | | | 1.00E-08 | 1.77E-08 | 6.30E-09 | 1.48E-08 | 8.10E-09 | | |
| Comanche Peak | 4.20E-07 | | | 1.24E-08 | | | 5.29E-09 | | | | | | | | | | |
| Seabrook | | 5.72E-06 | 5.21E-06 | 2.21E-09 | | | | | | | | 5.37E-08 | 3.80E-08 | 1.55E-06 | 1.62E-07 | | |
| Sizewell B | | | | | | | 1.03E-06 | 5.84E-07 | 1.05E-06 | 4.45E-07 | 2.12E-06 | 7.98E-07 | 7.77E-07 | 1.30E-06 | 4.14E-07 | 4.32E-06 | 5.07E-06 |
| Takahama | | | | | | | | | | | | | | | | | |

| | |
|---|---|
| Mean | 2.72E-06 |
| Standard Deviation | 5.45E-06 |
| Maximum | 8.17E-06 |
| Minimum | -2.74E-06 |
| Prediction | 1.79E-04 |

**Candidate Reactor** — **Normalised Data (Thermal) – GBq/GWth**

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaver Valley | 5.63E-07 | 3.25E-06 | 7.52E-07 | **1.81E-05** | 1.11E-06 | **1.97E-05** | 1.42E-06 | 8.82E-07 | | 8.70E-06 | 5.55E-07 | 2.82E-07 | 6.47E-06 | 2.36E-06 | 3.72E-08 | | |
| Byron | 3.74E-08 | 8.59E-09 | | 4.75E-09 | | 1.75E-08 | 8.59E-08 | | | | 3.24E-09 | 5.74E-09 | 2.04E-09 | 4.81E-09 | 2.62E-09 | | |
| Comanche Peak | 1.42E-07 | | | 3.84E-09 | | | 1.64E-09 | | | | | | | | | | |
| Seabrook | | 1.95E-06 | 1.78E-06 | 7.53E-10 | | | | | | | | 1.83E-08 | 1.29E-08 | 5.28E-07 | 5.51E-08 | | |
| Sizewell B | | | | | | | 3.57E-07 | 2.04E-07 | 3.65E-07 | 1.55E-07 | 7.39E-07 | 2.78E-07 | 2.70E-07 | 4.52E-07 | 1.44E-07 | 1.51E-06 | 1.77E-06 |
| Takahama | | | | | | | | | | | | | | | | | |

| | |
|---|---|
| Mean | 8.67E-07 |
| Standard Deviation | 1.69E-06 |
| Maximum | 2.56E-06 |
| Minimum | -8.27E-07 |
| Prediction | 5.85E-05 |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ⬜ | RIFE Reports (RIFE, 1995-2006) |

Data marked in red, has been excluded from the mean and standard deviation calculations

## Table D.7 Airborne carbon-14 discharges for AP1000 predecessors.

| Candidate Reactor | Raw Data – GBq | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Beaver Valley | | | | | | | | | | | | | | | | | |
| Byron | | | | | | | | | | | | | | | | | |
| Comanche Peak | | | | | | | | | | | | | | | | | |
| Seabrook | | | | | | | | | | | | | | | | | |
| Sizewell B | | | | | | | 5.41E+01 | 7.59E+01 | 2.30E+02 | 2.32E+01 | 1.76E+02 | 1.79E+02 | 1.94E+02 | 2.82E+02 | 1.99E+02 | 2.09E+02 | 1.69E+02 |
| Takahama | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 1.63E+02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 7.90E+01 | | | | | | | | | | | | | | | | |
| Maximum | 2.42E+02 | | | | | | | | | | | | | | | | |
| Minimum | 8.38E+01 | | | | | | | | | | | | | | | | |
| Prediction | 2.70E+02 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Electrical) – GBq/GWeh | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Beaver Valley | | | | | | | | | | | | | | | | | |
| Byron | | | | | | | | | | | | | | | | | |
| Comanche Peak | | | | | | | | | | | | | | | | | |
| Seabrook | | | | | | | | | | | | | | | | | |
| Sizewell B | | | | | | | 6.37E-03 | 8.96E-03 | 2.27E-02 | 2.91E-03 | 2.06E-02 | 1.95E-02 | 2.11E-02 | 3.18E-02 | 2.13E-02 | 2.40E-02 | 1.90E-02 |
| Takahama | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 1.80E-02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 8.52E-03 | | | | | | | | | | | | | | | | |
| Maximum | 2.66E-02 | | | | | | | | | | | | | | | | |
| Minimum | 9.51E-03 | | | | | | | | | | | | | | | | |
| Prediction | 2.76E-02 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Thermal) – GBq/GWth | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Beaver Valley | | | | | | | | | | | | | | | | | |
| Byron | | | | | | | | | | | | | | | | | |
| Comanche Peak | | | | | | | | | | | | | | | | | |
| Seabrook | | | | | | | | | | | | | | | | | |
| Sizewell B | | | | | | | 2.22E-03 | 3.12E-03 | 7.91E-03 | 1.02E-03 | 7.19E-03 | 6.78E-03 | 7.35E-03 | 1.11E-02 | 7.43E-03 | 8.37E-03 | 6.61E-03 |
| Takahama | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 6.28E-03 | | | | | | | | | | | | | | | | |
| Standard Deviation | 2.97E-03 | | | | | | | | | | | | | | | | |
| Maximum | 9.25E-03 | | | | | | | | | | | | | | | | |
| Minimum | 3.31E-03 | | | | | | | | | | | | | | | | |
| Prediction | 9.03E-03 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ▨ | RIFE Reports (RIFE, 1995-2006) |

# Appendix E: Discharge data for EPR predecessors

## Table E.1 Liquid tritium discharges for EPR predecessors.

| **Candidate Reactor** | **Raw Data – GBq** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | 1.30E+04 | 1.00E+04 | 2.00E+04 | 3.70E+04 | 3.90E+04 | 4.13E+04 | 2.81E+04 | | | |
| Civaux | | | | | | | | | | 3.60E+03 | 2.60E+04 | 1.60E+04 | 1.78E+04 | 2.42E+04 | | | |
| Emsland | 8.70E+03 | 8.30E+03 | 1.30E+04 | 9.50E+03 | 1.30E+04 | 1.00E+04 | 1.20E+04 | 1.50E+04 | 1.50E+04 | 1.70E+04 | 1.30E+04 | 1.80E+04 | 1.50E+04 | 1.50E+04 | | | |
| Golfech | 5.00E+02 | 8.00E+03 | 9.00E+03 | 8.40E+03 | 3.00E+04 | 2.70E+04 | 2.20E+04 | 3.30E+04 | 2.40E+04 | 2.30E+04 | 2.70E+04 | 4.90E+04 | 7.02E+04 | 6.75E+04 | | | |
| Neckarwestheim | 2.70E+04 | 3.20E+04 | 2.40E+04 | 3.00E+04 | 3.80E+04 | 3.50E+04 | 3.40E+04 | 3.30E+04 | 2.60E+04 | 2.37E+04 | 1.97E+04 | 1.90E+04 | 2.90E+04 | 3.30E+04 | | | |
| Isar-2 | 7.20E+03 | 8.60E+03 | 1.60E+04 | 1.90E+04 | 2.20E+04 | 1.90E+04 | 2.00E+04 | 1.70E+04 | 1.90E+04 | 2.40E+04 | 1.80E+04 | 2.00E+04 | 1.90E+04 | 2.00E+04 | | | |
| Penly | 4.00E+03 | 1.60E+04 | 2.00E+04 | 3.30E+04 | 2.30E+04 | 2.40E+04 | 2.90E+04 | 2.40E+04 | 3.20E+04 | 3.30E+04 | 3.50E+04 | 4.50E+04 | 3.32E+04 | 2.63E+04 | | | |
| Mean | 2.30E+04 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.23E+04 | | | | | | | | | | | | | | | | |
| Maximum | 3.53E+04 | | | | | | | | | | | | | | | | |
| Minimum | 1.07E+04 | | | | | | | | | | | | | | | | |
| Prediction | 1.04E+05 | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Electrical) – GBq/GWeh** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | 1.49E+00 | 6.15E+00 | 1.64E+00 | 2.37E+00 | 1.98E+00 | 2.14E+00 | 1.37E+00 | | | |
| Civaux | | | | | | | | | | 1.23E+00 | 1.86E+00 | 1.44E+00 | 1.04E+00 | 1.21E+00 | | | |
| Emsland | 8.67E-01 | 8.94E-01 | 1.28E+00 | 9.07E-01 | 1.23E+00 | 9.53E-01 | 1.14E+00 | 1.41E+00 | 1.39E+00 | 1.58E+00 | 1.20E+00 | 1.65E+00 | 1.33E+00 | 1.35E+00 | | | |
| Golfech | 2.75E-01 | 8.39E-01 | 1.27E+00 | 8.31E-01 | 1.99E+00 | 1.81E+00 | 1.23E+00 | 1.85E+00 | 1.42E+00 | 1.32E+00 | 1.53E+00 | 2.98E+00 | 3.68E+00 | 3.76E+00 | | | |
| Neckarwestheim | 1.75E+00 | 2.16E+00 | 1.55E+00 | 1.94E+00 | 2.29E+00 | 2.12E+00 | 2.04E+00 | 2.02E+00 | 1.57E+00 | 1.45E+00 | 1.19E+00 | 1.16E+00 | 1.81E+00 | 1.99E+00 | | | |
| Isar-2 | 7.77E-01 | 8.87E-01 | 1.63E+00 | 1.86E+00 | 2.10E+00 | 1.89E+00 | 1.95E+00 | 1.56E+00 | 1.77E+00 | 2.07E+00 | 1.59E+00 | 1.70E+00 | 1.65E+00 | 1.71E+00 | | | |
| Penly | 1.39E+00 | 1.90E+00 | 1.53E+00 | 1.98E+00 | 1.37E+00 | 1.41E+00 | 1.50E+00 | 1.45E+00 | 1.70E+00 | 1.98E+00 | 1.96E+00 | 2.41E+00 | 2.13E+00 | 1.35E+00 | | | |
| Mean | 1.68E+00 | | | | | | | | | | | | | | | | |
| Standard Deviation | 7.44E-01 | | | | | | | | | | | | | | | | |
| Maximum | 2.43E+00 | | | | | | | | | | | | | | | | |
| Minimum | 9.40E-01 | | | | | | | | | | | | | | | | |
| Prediction | 3.58E+00 | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Thermal) – GBq/GWth** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | 5.22E-01 | 2.16E+00 | 5.76E-01 | 8.31E-01 | 6.96E-01 | 7.51E-01 | 4.82E-01 | | | |
| Civaux | | | | | | | | | | 4.31E-01 | 6.49E-01 | 5.04E-01 | 3.64E-01 | 4.22E-01 | | | |
| Emsland | 2.99E-01 | 3.08E-01 | 4.42E-01 | 3.13E-01 | 4.26E-01 | 3.29E-01 | 3.92E-01 | 4.86E-01 | 4.80E-01 | 5.47E-01 | 4.15E-01 | 5.68E-01 | 4.61E-01 | 4.67E-01 | | | |
| Golfech | 9.43E-02 | 2.88E-01 | 4.37E-01 | 2.85E-01 | 6.85E-01 | 6.21E-01 | 4.22E-01 | 6.36E-01 | 4.86E-01 | 4.53E-01 | 5.25E-01 | 1.02E+00 | 1.26E+00 | 1.29E+00 | | | |
| Neckarwestheim | 5.66E-01 | 6.98E-01 | 5.02E-01 | 6.28E-01 | 7.40E-01 | 6.87E-01 | 6.60E-01 | 6.54E-01 | 5.09E-01 | 4.70E-01 | 3.84E-01 | 3.75E-01 | 5.86E-01 | 6.45E-01 | | | |
| Isar-2 | 2.82E-01 | 3.22E-01 | 5.91E-01 | 6.78E-01 | 7.62E-01 | 6.88E-01 | 7.08E-01 | 5.67E-01 | 6.42E-01 | 7.52E-01 | 5.80E-01 | 6.20E-01 | 6.00E-01 | 6.23E-01 | | | |
| Penly | 4.83E-01 | 6.61E-01 | 5.33E-01 | 6.91E-01 | 4.79E-01 | 4.91E-01 | 5.24E-01 | 5.05E-01 | 5.92E-01 | 6.91E-01 | 6.83E-01 | 8.41E-01 | 7.41E-01 | 4.70E-01 | | | |
| Mean | 5.82E-01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 2.59E-01 | | | | | | | | | | | | | | | | |
| Maximum | 8.41E-01 | | | | | | | | | | | | | | | | |
| Minimum | 3.23E-01 | | | | | | | | | | | | | | | | |
| Prediction | 1.32E+00 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ⬜ | RIFE Reports (RIFE, 1995-2006) |

## Table E.2 Other liquid discharges for EPR predecessors.

| **Candidate Reactor** | **Raw Data – GBq** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | 1.90E+00 | 1.70E+00 | 8.92E-01 | 1.77E+00 | 6.59E-01 | 7.36E-01 | 7.62E-01 | | | |
| Civaux | | | | | | | | | | 3.94E-01 | 1.26E+00 | 1.65E+00 | 1.14E+00 | 6.09E-01 | | | |
| Emsland | 8.70E-03 | 3.30E-03 | 6.50E-04 | 6.00E-04 | 7.00E-04 | 2.10E-04 | 1.00E-05 | | 9.40E-06 | | 1.06E-04 | 1.40E-04 | 1.75E-05 | | | | |
| Golfech | 2.80E-01 | 7.00E-02 | 7.00E-01 | 1.10E+00 | 2.30E+00 | 4.80E+00 | 1.70E+00 | 2.80E+00 | 9.30E-01 | 1.50E+00 | 6.17E-01 | 5.83E-01 | 8.44E-01 | 1.37E+00 | | | |
| Neckarwestheim | 9.10E-02 | 9.80E-02 | 4.50E-02 | 2.10E-02 | 1.60E-02 | 2.80E-02 | 1.04E-01 | 2.60E-02 | 5.43E-02 | 3.79E-02 | 1.79E-03 | 1.95E-03 | 1.72E-01 | 1.89E-02 | | | |
| Isar-2 | 6.00E-02 | 3.90E-03 | 9.50E-03 | 8.30E-03 | 4.00E-04 | 0.00E+00 | 2.90E-04 | 3.80E-04 | 2.60E-04 | 9.50E-04 | 3.73E-02 | 9.50E-05 | 8.30E-05 | | | | |
| Penly | 2.60E+01 | 2.00E+00 | 4.00E+00 | 3.80E+00 | 3.30E+00 | 1.80E+00 | 1.60E+00 | 1.70E+00 | 1.60E+00 | 1.32E+00 | 1.18E+00 | 1.10E+00 | 1.71E+00 | 2.03E+00 | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 7.93E-01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.06E+00 | | | | | | | | | | | | | | | | |
| Maximum | 1.85E+00 | | | | | | | | | | | | | | | | |
| Minimum | -2.65E-01 | | | | | | | | | | | | | | | | |
| Prediction | 4.72E+01 | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Electrical) – GBq/GWeh** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | 2.17E-04 | 1.05E-03 | 7.31E-05 | 1.13E-04 | 3.35E-05 | 3.81E-05 | 3.72E-05 | | | |
| Civaux | | | | | | | | | | 1.35E-04 | 9.01E-05 | 1.49E-04 | 6.69E-05 | 3.04E-05 | | | |
| Emsland | 8.67E-07 | 3.55E-07 | 6.40E-08 | 5.73E-08 | 6.65E-08 | 2.00E-08 | 9.47E-10 | | 8.71E-10 | | 9.81E-09 | 1.28E-08 | 1.56E-09 | | | | |
| Golfech | 1.54E-04 | 7.34E-06 | 9.91E-05 | 1.09E-04 | 1.53E-04 | 3.22E-04 | 9.51E-05 | 1.57E-04 | 5.49E-05 | 8.60E-05 | 3.50E-05 | 3.54E-05 | 4.42E-05 | 7.63E-05 | | | |
| Neckarwestheim | 5.89E-06 | 6.60E-06 | 2.91E-06 | 1.36E-06 | 9.62E-07 | 1.70E-06 | 6.24E-06 | 1.59E-06 | 3.29E-06 | 2.32E-06 | 1.08E-07 | 1.19E-07 | 1.07E-05 | 1.14E-06 | | | |
| Isar-2 | 6.47E-06 | 4.02E-07 | 9.65E-07 | 8.14E-07 | 3.81E-08 | 0.00E+00 | 2.83E-08 | 3.48E-08 | 2.42E-08 | 8.18E-08 | 3.30E-06 | 8.10E-09 | 7.21E-09 | | | | |
| Penly | 9.01E-03 | 2.37E-04 | 3.06E-04 | 2.28E-04 | 1.97E-04 | 1.06E-04 | 8.30E-05 | 1.03E-04 | 8.49E-05 | 7.93E-05 | 6.61E-05 | 5.90E-05 | 1.10E-04 | 1.04E-04 | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 6.85E-05 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.35E-04 | | | | | | | | | | | | | | | | |
| Maximum | 2.04E-04 | | | | | | | | | | | | | | | | |
| Minimum | -6.69E-05 | | | | | | | | | | | | | | | | |
| Prediction | 1.62E-03 | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Thermal) – GBq/GWth** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | 7.63E-05 | 3.67E-04 | 2.57E-05 | 3.97E-05 | 1.18E-05 | 1.34E-05 | 1.31E-05 | | | |
| Civaux | | | | | | | | | | 4.71E-05 | 3.14E-05 | 5.19E-05 | 2.33E-05 | 1.06E-05 | | | |
| Emsland | 2.99E-07 | 1.23E-07 | 2.21E-08 | 1.98E-08 | 2.30E-08 | 6.91E-09 | 3.27E-10 | | 3.01E-10 | | 3.39E-09 | 4.42E-09 | 5.37E-10 | | | | |
| Golfech | 5.28E-05 | 2.52E-06 | 3.40E-05 | 3.74E-05 | 5.25E-05 | 1.10E-04 | 3.26E-05 | 5.40E-05 | 1.88E-05 | 2.95E-05 | 1.20E-05 | 1.21E-05 | 1.52E-05 | 2.62E-05 | | | |
| Neckarwestheim | 1.91E-06 | 2.14E-06 | 9.41E-07 | 4.39E-07 | 3.11E-07 | 5.49E-07 | 2.02E-06 | 5.15E-07 | 1.06E-06 | 7.52E-07 | 3.49E-08 | 3.84E-08 | 3.47E-06 | 3.70E-07 | | | |
| Isar-2 | 2.35E-06 | 1.46E-07 | 3.51E-07 | 2.96E-07 | 1.39E-08 | 0.00E+00 | 1.03E-08 | 1.27E-08 | 8.79E-09 | 2.98E-08 | 1.20E-06 | 2.94E-09 | 2.62E-09 | | | | |
| Penly | 3.14E-03 | 8.26E-05 | 1.07E-04 | 7.96E-05 | 6.87E-05 | 3.68E-05 | 2.89E-05 | 3.57E-05 | 2.96E-05 | 2.76E-05 | 2.30E-05 | 2.06E-05 | 3.82E-05 | 3.63E-05 | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 2.38E-05 | | | | | | | | | | | | | | | | |
| Standard Deviation | 4.74E-05 | | | | | | | | | | | | | | | | |
| Maximum | 7.13E-05 | | | | | | | | | | | | | | | | |
| Minimum | -2.36E-05 | | | | | | | | | | | | | | | | |
| Prediction | 5.99E-04 | | | | | | | | | | | | | | | | |

| **Colour Code** | **Information source** |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ⬜ | RIFE Reports (RIFE, 1995-2006) |

## Table E.3 Airborne tritium discharges for EPR predecessors.

| Candidate Reactor | Raw Data – GBq | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | | | | | | 2.79E+02 | 4.24E+02 | | | |
| Civaux | | | | | | | | | | | | | 3.14E+02 | 5.29E+02 | | | |
| Emsland | 4.80E+02 | 6.70E+02 | 5.10E+02 | 7.80E+02 | 1.30E+03 | 1.60E+03 | 2.00E+03 | 1.90E+03 | 2.50E+03 | 2.50E+03 | 1.60E+03 | 1.50E+03 | 1.40E+03 | 1.60E+03 | | | |
| Golfech | | | | | | | | | | | | | 2.27E+03 | 2.16E+03 | | | |
| Neckarwestheim | 1.09E+03 | 1.23E+03 | 9.00E+02 | 9.80E+02 | 6.30E+02 | 6.00E+02 | 4.50E+02 | 3.90E+02 | 4.30E+02 | 3.90E+02 | 3.60E+02 | 2.60E+02 | 3.20E+02 | 2.80E+02 | | | |
| Isar-2 | 8.90E+02 | 9.50E+02 | 1.30E+03 | 1.40E+03 | 1.30E+03 | 1.30E+03 | 1.30E+03 | 9.70E+02 | 9.90E+02 | 4.80E+02 | 5.90E+02 | 3.00E+02 | 3.70E+02 | 4.00E+02 | | | |
| Chooz | | | | | | | | | | | | | 2.52E+03 | 2.47E+03 | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 1.04E+03 | | | | | | | | | | | | | | | | |
| Standard Deviation | 6.90E+02 | | | | | | | | | | | | | | | | |
| Maximum | 1.73E+03 | | | | | | | | | | | | | | | | |
| Minimum | 3.53E+02 | | | | | | | | | | | | | | | | |
| Prediction | 5.00E+02 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Electrical) – GBq/GWeh | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | | | | | | 1.44E-02 | 2.07E-02 | | | |
| Civaux | | | | | | | | | | | | | 1.84E-02 | 2.64E-02 | | | |
| Emsland | 4.78E-02 | 7.21E-02 | 5.02E-02 | 7.44E-02 | 1.23E-01 | 1.52E-01 | 1.89E-01 | 1.78E-01 | 2.32E-01 | 2.33E-01 | 1.48E-01 | 1.37E-01 | 1.25E-01 | 1.44E-01 | | | |
| Golfech | | | | | | | | | | | | | 1.19E-01 | 1.20E-01 | | | |
| Neckarwestheim | 7.06E-02 | 8.29E-02 | 5.82E-02 | 6.33E-02 | 3.79E-02 | 3.64E-02 | 2.70E-02 | 2.39E-02 | 2.60E-02 | 2.39E-02 | 2.17E-02 | 1.58E-02 | 2.00E-02 | 1.69E-02 | | | |
| Isar-2 | 9.60E-02 | 9.79E-02 | 1.32E-01 | 1.37E-01 | 1.24E-01 | 1.29E-01 | 1.27E-01 | 8.89E-02 | 9.20E-02 | 4.13E-02 | 5.23E-02 | 2.56E-02 | 3.21E-02 | 3.43E-02 | | | |
| Chooz | | | | | | | | | | | | | 1.44E-02 | 2.07E-02 | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 8.50E-02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 5.91E-02 | | | | | | | | | | | | | | | | |
| Maximum | 1.44E-01 | | | | | | | | | | | | | | | | |
| Minimum | 2.59E-02 | | | | | | | | | | | | | | | | |
| Prediction | 3.44E-02 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Thermal) – GBq/GWth | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | | | | | | 5.07E-03 | 7.27E-03 | | | |
| Civaux | | | | | | | | | | | | | 6.43E-03 | 9.22E-03 | | | |
| Emsland | 1.65E-02 | 2.49E-02 | 1.73E-02 | 2.57E-02 | 4.26E-02 | 5.26E-02 | 6.54E-02 | 6.16E-02 | 7.99E-02 | 8.04E-02 | 5.11E-02 | 4.74E-02 | 4.30E-02 | 4.98E-02 | | | |
| Golfech | | | | | | | | | | | | | 4.08E-02 | 4.13E-02 | | | |
| Neckarwestheim | 2.28E-02 | 2.68E-02 | 1.88E-02 | 2.05E-02 | 1.23E-02 | 1.18E-02 | 8.74E-03 | 7.72E-03 | 8.42E-03 | 7.74E-03 | 7.01E-03 | 5.13E-03 | 6.46E-03 | 5.47E-03 | | | |
| Isar-2 | 3.49E-02 | 3.56E-02 | 4.80E-02 | 4.99E-02 | 4.50E-02 | 4.71E-02 | 4.61E-02 | 3.23E-02 | 3.35E-02 | 1.50E-02 | 1.90E-02 | 9.30E-03 | 1.17E-02 | 1.25E-02 | | | |
| Penly | | | | | | | | | | | | | 5.62E-02 | 4.41E-02 | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 2.96E-02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 2.07E-02 | | | | | | | | | | | | | | | | |
| Maximum | 5.03E-02 | | | | | | | | | | | | | | | | |
| Minimum | 8.85E-03 | | | | | | | | | | | | | | | | |
| Prediction | 1.27E-02 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ▨ | RIFE Reports (RIFE, 1995-2006) |

## Table E.4 Airborne noble gas discharges for EPR predecessors.

| **Candidate Reactor** | **Raw Data – GBq** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | 0.00E+00 | | | | | | | | | |
| Civaux | | | | | | | | | | | | | | | | | |
| Emsland | 9.80E+01 | 1.10E+02 | 1.00E+02 | 2.70E+02 | 6.10E+02 | 6.00E+02 | 1.20E+02 | 1.00E+02 | 1.90E+03 | 9.70E+02 | | | | | | | |
| Golfech | 6.40E+03 | 1.00E+04 | 7.70E+03 | 1.00E+04 | 1.60E+04 | 1.40E+04 | 1.40E+04 | 2.20E+04 | | | | | | | | | |
| Neckarwestheim | 1.82E+04 | 1.35E+04 | 1.55E+04 | 6.10E+03 | 4.00E+03 | 3.70E+02 | 4.60E+03 | 2.15E+03 | 1.06E+03 | 9.80E+02 | | | | | | | |
| Isar-2 | 2.20E+02 | 2.40E+02 | 2.80E+02 | 3.30E+02 | 1.50E+02 | 2.20E+02 | 1.70E+02 | 1.70E+02 | 2.90E+02 | 5.00E+02 | 2.28E+02 | 3.34E+02 | 2.81E+02 | 2.20E+02 | | | |
| Penly | 8.60E+03 | 1.10E+04 | 9.40E+03 | 1.20E+04 | 1.70E+04 | 9.90E+03 | 1.30E+04 | 1.30E+04 | | | | | | | | | |
| Mean | 5.27E+03 | | | | | | | | | | | | | | | | |
| Standard Deviation | 6.34E+03 | | | | | | | | | | | | | | | | |
| Maximum | 1.16E+04 | | | | | | | | | | | | | | | | |
| Minimum | -1.06E+03 | | | | | | | | | | | | | | | | |
| Prediction | 1.60E+03 | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Electrical) – GBq/GWeh** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | 0.00E+00 | | | | | | | | | |
| Civaux | | | | | | | | | | | | | | | | | |
| Emsland | 9.76E-03 | 1.18E-02 | 9.84E-03 | 2.58E-02 | 5.79E-02 | 5.72E-02 | 1.14E-02 | 9.39E-03 | 1.76E-01 | 9.04E-02 | | | | | | | |
| Golfech | 3.52E+00 | 1.05E+00 | 1.09E+00 | 9.90E-01 | 1.06E+00 | 9.38E-01 | 7.83E-01 | 1.24E+00 | | | | | | | | | |
| Neckarwestheim | 1.18E+00 | 9.10E-01 | 1.00E+00 | 3.94E-01 | 2.41E-01 | 2.24E-02 | 2.76E-01 | 1.32E-01 | 6.42E-02 | 6.01E-02 | | | | | | | |
| Isar-2 | 2.37E-02 | 2.47E-02 | 2.84E-02 | 3.24E-02 | 1.43E-02 | 2.19E-02 | 1.66E-02 | 1.56E-02 | 2.70E-02 | 4.31E-02 | 2.02E-02 | 2.85E-02 | 2.44E-02 | 1.88E-02 | | | |
| Penly | 2.98E+00 | 1.30E+00 | 7.19E-01 | 7.21E-01 | 1.02E+00 | 5.81E-01 | 6.74E-01 | 7.84E-01 | | | | | | | | | |
| Mean | 4.81E-01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 7.16E-01 | | | | | | | | | | | | | | | | |
| Maximum | 1.20E+00 | | | | | | | | | | | | | | | | |
| Minimum | -2.35E-01 | | | | | | | | | | | | | | | | |
| Prediction | 5.50E-02 | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Thermal) – GBq/GWth** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | 0.00E+00 | | | | | | | | | |
| Civaux | | | | | | | | | | | | | | | | | |
| Emsland | 3.37E-03 | 4.09E-03 | 3.40E-03 | 8.90E-03 | 2.00E-02 | 1.97E-02 | 3.92E-03 | 3.24E-03 | 6.08E-02 | 3.12E-02 | | | | | | | |
| Golfech | 1.21E+00 | 3.60E-01 | 3.74E-01 | 3.40E-01 | 3.65E-01 | 3.22E-01 | 2.69E-01 | 4.24E-01 | | | | | | | | | |
| Neckarwestheim | 3.81E-01 | 2.94E-01 | 3.24E-01 | 1.28E-01 | 7.78E-02 | 7.26E-03 | 8.93E-02 | 4.26E-02 | 2.08E-02 | 1.94E-02 | | | | | | | |
| Isar-2 | 8.63E-03 | 9.00E-03 | 1.03E-02 | 1.18E-02 | 5.19E-03 | 7.97E-03 | 6.02E-03 | 5.67E-03 | 9.80E-03 | 1.57E-02 | 7.34E-03 | 1.04E-02 | 8.88E-03 | 6.85E-03 | | | |
| Penly | 1.04E+00 | 4.54E-01 | 2.51E-01 | 2.51E-01 | 3.54E-01 | 2.02E-01 | 2.35E-01 | 2.73E-01 | | | | | | | | | |
| Mean | 1.64E-01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 2.46E-01 | | | | | | | | | | | | | | | | |
| Maximum | 4.11E-01 | | | | | | | | | | | | | | | | |
| Minimum | -8.19E-02 | | | | | | | | | | | | | | | | |
| Prediction | 2.03E-02 | | | | | | | | | | | | | | | | |

| **Colour Code** | **Information source** |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ⬜ | RIFE Reports (RIFE, 1995-2006) |

# Table E.5 Airborne iodine-131 discharges for EPR predecessors.

| Candidate Reactor | Raw Data – GBq | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | | | | | | 1.68E-01 | 8.17E-02 | | | |
| Civaux | | | | | | | | | | | | | 2.21E-03 | 2.36E-02 | | | |
| Emsland | | | 7.40E-05 | 3.40E-04 | 2.60E-03 | 1.30E-03 | | | 9.30E-04 | 2.00E-04 | | | | | | | |
| Golfech | | | | | | | | | | | | | 3.33E-02 | 4.07E-02 | | | |
| Neckarwestheim | 2.62E-02 | 8.20E-05 | 9.60E-04 | 6.70E-03 | 1.93E-02 | 2.02E-02 | 7.10E-04 | 4.17E-03 | 3.20E-04 | 2.60E-04 | 1.40E-04 | 4.20E-04 | 7.40E-04 | 1.04E-04 | | | |
| Isar-2 | | | 5.40E-04 | | | | | | | | | | | | | | |
| Penly | | | | | | | | | | | | | 8.45E-02 | 2.72E-02 | | | |
| Mean | 1.89E-02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 3.65E-02 | | | | | | | | | | | | | | | | |
| Maximum | 5.54E-02 | | | | | | | | | | | | | | | | |
| Minimum | -1.76E-02 | | | | | | | | | | | | | | | | |
| Prediction | 4.56E-02 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Electrical) – GBq/GWeh | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | | | | | | 8.69E-06 | 3.99E-06 | | | |
| Civaux | | | | | | | | | | | | | 1.30E-07 | 1.18E-06 | | | |
| Emsland | | | 7.28E-09 | 3.25E-08 | 2.47E-07 | 1.24E-07 | | | 8.62E-08 | 1.86E-08 | | | | | | | |
| Golfech | | | | | | | | | | | | | 1.74E-06 | 2.27E-06 | | | |
| Neckarwestheim | 1.70E-06 | 5.53E-09 | 6.20E-08 | 4.33E-07 | 1.16E-06 | 1.22E-06 | 4.26E-08 | 2.55E-07 | 1.94E-08 | 1.59E-08 | 8.43E-09 | 2.56E-08 | 4.62E-08 | 6.28E-09 | | | |
| Isar-2 | | | 5.49E-08 | | | | | | | | | | | | | | |
| Penly | | | | | | | | | | | | | 5.41E-06 | 1.39E-06 | | | |
| Mean | 1.05E-06 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.95E-06 | | | | | | | | | | | | | | | | |
| Maximum | 3.00E-06 | | | | | | | | | | | | | | | | |
| Minimum | -9.03E-07 | | | | | | | | | | | | | | | | |
| Prediction | 1.57E-06 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Thermal) – GBq/GWth | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | | | | | | 3.05E-06 | 1.40E-06 | | | |
| Civaux | | | | | | | | | | | | | 4.53E-08 | 4.11E-07 | | | |
| Emsland | | | 2.51E-09 | 1.12E-08 | 8.53E-08 | 4.28E-08 | | | 2.97E-08 | 6.43E-09 | | | | | | | |
| Golfech | | | | | | | | | | | | | 5.99E-07 | 7.78E-07 | | | |
| Neckarwestheim | 5.49E-07 | 1.79E-09 | 2.01E-08 | 1.40E-07 | 3.76E-07 | 3.96E-07 | 1.38E-08 | 8.26E-08 | 6.27E-09 | 5.16E-09 | 2.73E-09 | 8.28E-09 | 1.49E-08 | 2.03E-09 | | | |
| Isar-2 | | | 1.99E-08 | | | | | | | | | | | | | | |
| Penly | | | | | | | | | | | | | 1.89E-06 | 4.86E-07 | | | |
| Mean | 3.61E-07 | | | | | | | | | | | | | | | | |
| Standard Deviation | 6.83E-07 | | | | | | | | | | | | | | | | |
| Maximum | 1.04E-06 | | | | | | | | | | | | | | | | |
| Minimum | -3.22E-07 | | | | | | | | | | | | | | | | |
| Prediction | 5.78E-07 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ⬜ | RIFE Reports (RIFE, 1995-2006) |

# Table E.6 Airborne particulate discharges for EPR predecessors.

| Candidate Reactor | Raw Data – GBq | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | | | | | | 1.92E-02 | 1.61E-02 | | | |
| Civaux | | | | | | | | | | | | | 3.46E-03 | 4.54E-03 | | | |
| Emsland | 6.00E-04 | 3.90E-04 | 3.70E-04 | 7.10E-05 | 6.80E-04 | 7.00E-06 | 6.60E-04 | 1.70E-04 | | 0.00E+00 | 2.57E-04 | 2.97E-04 | 2.30E-05 | 4.00E-05 | | | |
| Golfech | | | | | | | | | | | | | 5.56E-03 | 1.47E-02 | | | |
| Neckarwestheim | 6.30E-03 | 3.40E-03 | 2.60E-03 | 1.60E-03 | 7.10E-03 | 1.20E-03 | 2.90E-03 | 2.70E-04 | | 2.64E-04 | 5.51E-03 | 2.16E-03 | 3.49E-04 | 4.92E-06 | | | |
| Isar-2 | 3.70E-05 | 1.30E-05 | 3.40E-04 | 3.60E-05 | 0.00E+00 | 0.00E+00 | 1.80E-03 | 7.00E-05 | 0.00E+00 | 0.00E+00 | | | | | | | |
| Penly | | | | | | | | | | | | | 6.44E-03 | 1.88E-03 | | | |
| Mean | 2.53E-03 | | | | | | | | | | | | | | | | |
| Standard Deviation | 4.40E-03 | | | | | | | | | | | | | | | | |
| Maximum | 6.93E-03 | | | | | | | | | | | | | | | | |
| Minimum | -1.87E-03 | | | | | | | | | | | | | | | | |
| Prediction | 4.00E-03 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Electrical) – GBq/GWeh | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | | | | | | 9.93E-07 | 7.86E-07 | | | |
| Civaux | | | | | | | | | | | | | 2.03E-07 | 2.27E-07 | | | |
| Emsland | 5.98E-08 | 4.20E-08 | 3.64E-08 | 6.78E-09 | 6.46E-08 | 6.67E-10 | 6.25E-08 | 1.60E-08 | | 0.00E+00 | 2.38E-08 | 2.72E-08 | 2.05E-09 | 3.60E-09 | | | |
| Golfech | | | | | | | | | | | | | 2.91E-07 | 8.19E-07 | | | |
| Neckarwestheim | 4.08E-07 | 2.29E-07 | 1.68E-07 | 1.03E-07 | 4.27E-07 | 7.27E-08 | 1.74E-07 | 1.65E-08 | | 1.62E-08 | 3.31E-07 | 1.31E-07 | 2.18E-08 | 2.97E-10 | | | |
| Isar-2 | 3.99E-09 | 1.34E-09 | 3.45E-08 | 3.53E-09 | 0.00E+00 | 0.00E+00 | 1.75E-07 | 6.42E-09 | 0.00E+00 | 0.00E+00 | | | | | | | |
| Penly | | | | | | | | | | | | | 4.13E-07 | 9.64E-08 | | | |
| Mean | 1.48E-07 | | | | | | | | | | | | | | | | |
| Standard Deviation | 2.32E-07 | | | | | | | | | | | | | | | | |
| Maximum | 3.80E-07 | | | | | | | | | | | | | | | | |
| Minimum | -8.48E-08 | | | | | | | | | | | | | | | | |
| Prediction | 2.75E-07 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Thermal) – GBq/GWth | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | | | | | | 3.49E-07 | 2.76E-07 | | | |
| Civaux | | | | | | | | | | | | | 7.09E-08 | 7.91E-08 | | | |
| Emsland | 2.06E-08 | 1.45E-08 | 1.26E-08 | 2.34E-09 | 2.23E-08 | 2.30E-10 | 2.16E-08 | 5.51E-09 | | 0.00E+00 | 8.21E-09 | 9.38E-09 | 7.06E-10 | 1.24E-09 | | | |
| Golfech | | | | | | | | | | | | | 1.00E-07 | 2.81E-07 | | | |
| Neckarwestheim | 1.32E-07 | 7.41E-08 | 5.44E-08 | 3.35E-08 | 1.38E-07 | 2.35E-08 | 5.63E-08 | 5.35E-09 | | 5.24E-09 | 1.07E-07 | 4.25E-08 | 7.05E-09 | 9.61E-11 | | | |
| Isar-2 | 1.45E-09 | 4.87E-10 | 1.26E-08 | 1.28E-09 | 0.00E+00 | 0.00E+00 | 6.38E-08 | 2.33E-09 | 0.00E+00 | 0.00E+00 | | | | | | | |
| Penly | | | | | | | | | | | | | 1.44E-07 | 3.36E-08 | | | |
| Mean | 5.03E-08 | | | | | | | | | | | | | | | | |
| Standard Deviation | 8.04E-08 | | | | | | | | | | | | | | | | |
| Maximum | 1.31E-07 | | | | | | | | | | | | | | | | |
| Minimum | -3.01E-08 | | | | | | | | | | | | | | | | |
| Prediction | 1.01471E-07 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ⬜ | RIFE Reports (RIFE, 1995-2006) |

## Table E.7 Airborne carbon-14 discharges for EPR predecessors.

| Candidate Reactor | Raw Data – GBq | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | | | | | | 4.26E+02 | 4.88E+02 | | | |
| Civaux | | | | | | | | | | | | | 4.55E+02 | 4.78E+02 | | | |
| Emsland | | | | | | 1.30E+02 | 1.80E+02 | 2.50E+02 | 5.90E+02 | 7.00E+02 | 3.20E+02 | 3.60E+02 | 4.00E+02 | 4.80E+02 | | | |
| Golfech | | | | | | | | | | | | | 4.54E+02 | 4.28E+02 | | | |
| Neckarwestheim | | | | | | 8.00E+01 | 1.87E+02 | 2.20E+02 | 4.00E+02 | 5.10E+02 | 6.30E+02 | 4.30E+02 | 4.50E+02 | 5.10E+02 | | | |
| Isar-2 | | | | | | 4.50E+02 | 4.70E+02 | 5.20E+02 | 5.00E+02 | 5.40E+02 | 5.80E+02 | 1.20E+02 | 4.50E+02 | 3.50E+02 | | | |
| Penly | | | | | | | | | | | | | 3.72E+02 | 4.64E+02 | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 4.11E+02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.47E+02 | | | | | | | | | | | | | | | | |
| Maximum | 5.58E+02 | | | | | | | | | | | | | | | | |
| Minimum | 2.64E+02 | | | | | | | | | | | | | | | | |
| Prediction | 3.50E+02 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Electrical) – GBq/GWeh | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | | | | | | 2.20E-02 | 2.38E-02 | | | |
| Civaux | | | | | | | | | | | | | 2.67E-02 | 2.39E-02 | | | |
| Emsland | | | | | | 1.24E-02 | 1.70E-02 | 2.35E-02 | 5.47E-02 | 6.52E-02 | 2.96E-02 | 3.29E-02 | 3.56E-02 | 4.33E-02 | | | |
| Golfech | | | | | | | | | | | | | 2.38E-02 | 2.38E-02 | | | |
| Neckarwestheim | | | | | | 4.85E-03 | 1.12E-02 | 1.34E-02 | 2.42E-02 | 3.13E-02 | 3.79E-02 | 2.62E-02 | 2.81E-02 | 3.08E-02 | | | |
| Isar-2 | | | | | | 4.48E-02 | 4.58E-02 | 4.77E-02 | 4.65E-02 | 4.65E-02 | 5.14E-02 | 1.02E-02 | 3.91E-02 | 3.00E-02 | | | |
| Penly | | | | | | | | | | | | | 2.38E-02 | 2.38E-02 | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 3.07E-02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.38E-02 | | | | | | | | | | | | | | | | |
| Maximum | 4.46E-02 | | | | | | | | | | | | | | | | |
| Minimum | 1.69E-02 | | | | | | | | | | | | | | | | |
| Prediction | 2.41E-02 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Thermal) – GBq/GWth | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chooz | | | | | | | | | | | | | 7.74E-03 | 8.36E-03 | | | |
| Civaux | | | | | | | | | | | | | 9.32E-03 | 8.33E-03 | | | |
| Emsland | | | | | | 4.28E-03 | 5.89E-03 | 8.10E-03 | 1.89E-02 | 2.25E-02 | 1.02E-02 | 1.14E-02 | 1.23E-02 | 1.49E-02 | | | |
| Golfech | | | | | | | | | | | | | 8.16E-03 | 8.18E-03 | | | |
| Neckarwestheim | | | | | | 1.57E-03 | 3.64E-03 | 4.35E-03 | 7.84E-03 | 1.01E-02 | 1.23E-02 | 8.48E-03 | 9.09E-03 | 9.96E-03 | | | |
| Isar-2 | | | | | | 1.63E-02 | 1.66E-02 | 1.73E-02 | 1.69E-02 | 1.69E-02 | 1.87E-02 | 3.72E-03 | 1.42E-02 | 1.09E-02 | | | |
| Penly | | | | | | | | | | | | | 8.30E-03 | 8.29E-03 | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 1.07E-02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 5.00E-03 | | | | | | | | | | | | | | | | |
| Maximum | 1.57E-02 | | | | | | | | | | | | | | | | |
| Minimum | 5.69E-03 | | | | | | | | | | | | | | | | |
| Prediction | 8.88E-03 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ⬜ | RIFE Reports (RIFE, 1995-2006) |

# Appendix F: Discharge data for ESBWR predecessors

## Table F.1 Liquid tritium discharges for ESBWR predecessors.

| **Candidate Reactor** | **Raw Data – GBq** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 9.62E+01 | 1.65E+02 | 8.73E+01 | | | | | | | | | | | | | | |
| Hamaoka | **2.10E+03** | 1.30E+03 | 1.00E+03 | 1.40E+03 | 1.30E+03 | 1.00E+03 | 6.80E+02 | 6.00E+02 | 1.30E+03 | 9.40E+02 | 6.10E+02 | 6.20E+02 | 7.50E+02 | 5.90E+02 | 4.60E+02 | 7.50E+02 | 6.80E+02 |
| Kashiwazaki | 1.50E+02 | 4.20E+01 | 3.90E+02 | 1.60E+02 | 1.60E+02 | 1.30E+02 | 1.70E+02 | 8.00E+01 | 4.50E+02 | 9.30E+02 | 9.60E+02 | 4.10E+02 | 1.20E+02 | 8.50E+02 | 4.90E+02 | 8.10E+02 | 8.80E+02 |
| Nile Mile Point | 2.29E+02 | 2.88E+02 | 3.31E+02 | 8.77E+02 | 6.54E+02 | 7.07E+02 | | | | | | 3.11E+01 | 4.60E+01 | 9.36E+00 | 5.85E+00 | | |
| Shika | | | | 1.60E+01 | 5.70E+01 | 1.40E+02 | 1.70E+02 | 2.00E+02 | 3.30E+00 | 1.60E+02 | 1.60E+02 | 1.80E+02 | 6.50E+01 | 2.20E+02 | 4.50E+02 | 7.50E+02 | 6.80E+02 |
| Shimane | 4.30E+02 | 5.10E+02 | 4.30E+02 | 5.70E+02 | 1.00E+03 | 7.30E+02 | **1.20E+03** | 7.20E+02 | 3.10E+02 | 3.70E+02 | 6.00E+02 | 5.20E+02 | 3.60E+02 | 5.20E+02 | 6.30E+02 | 6.30E+02 | 3.00E+02 |

| | |
|---|---|
| Mean | 4.81E+02 |
| Standard Deviation | 3.56E+02 |
| Maximum | 8.37E+02 |
| Minimum | 1.26E+02 |
| Prediction | 1.04E+03 |

| **Candidate Reactor** | **Normalised Data (Electrical) – GBq/GWeh** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 2.67E-02 | 2.73E-02 | 1.77E-02 | | | | | | | | | | | | | | |
| Hamaoka | **1.45E-01** | 9.14E-02 | 7.33E-02 | 6.12E-02 | 6.57E-02 | 3.61E-02 | 2.72E-02 | 2.38E-02 | 5.17E-02 | 3.72E-02 | 2.53E-02 | 2.64E-02 | 5.79E-02 | 4.85E-02 | 2.16E-02 | 2.75E-02 | 4.17E-02 |
| Kashiwazaki | 7.78E-03 | 1.84E-03 | 1.69E-02 | 5.36E-03 | 4.60E-03 | 3.26E-03 | 3.76E-03 | 1.38E-03 | 7.75E-03 | 1.54E-02 | 1.64E-02 | 7.35E-03 | 2.21E-03 | 4.28E-02 | 1.00E-02 | 1.66E-02 | 1.73E-02 |
| Nile Mile Point | 4.20E-02 | 2.76E-02 | 4.10E-02 | 7.60E-02 | 4.93E-02 | 6.21E-02 | | | | | | 2.35E-03 | 3.45E-03 | 6.72E-04 | 4.29E-04 | | |
| Shika | | | | 5.65E-03 | 1.72E-02 | 4.00E-02 | 4.92E-02 | 4.51E-02 | 9.35E-04 | 4.81E-02 | 4.25E-02 | 4.07E-02 | 1.84E-02 | 1.44E-01 | 1.27E-01 | 1.20E-01 | 9.12E-02 |
| Shimane | 4.85E-02 | 5.89E-02 | 5.25E-02 | 6.13E-02 | 1.18E-01 | 8.74E-02 | **1.53E-01** | 7.33E-02 | 3.16E-02 | 4.06E-02 | 8.04E-02 | 5.34E-02 | 3.81E-02 | 6.86E-02 | 7.84E-02 | 7.60E-02 | 3.85E-02 |

| | |
|---|---|
| Mean | 4.04E-02 |
| Standard Deviation | 3.25E-02 |
| Maximum | 7.29E-02 |
| Minimum | 7.92E-03 |
| Prediction | 3.79E-02 |

| **Candidate Reactor** | **Normalised Data (Thermal) – GBq/GWth** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 8.60E-03 | 8.77E-03 | 5.68E-03 | | | | | | | | | | | | | | |
| Hamaoka | **4.84E-02** | 3.05E-02 | 2.45E-02 | 2.04E-02 | 2.19E-02 | 1.20E-02 | 9.07E-03 | 7.93E-03 | 1.72E-02 | 1.24E-02 | 8.44E-03 | 8.82E-03 | 1.93E-02 | 1.62E-02 | 7.20E-03 | 9.17E-03 | 1.39E-02 |
| Kashiwazaki | 2.55E-03 | 6.04E-04 | 5.55E-03 | 1.76E-03 | 1.51E-03 | 1.07E-03 | 1.23E-03 | 4.52E-04 | 2.54E-03 | 5.03E-03 | 5.38E-03 | 2.41E-03 | 7.24E-04 | 1.40E-02 | 3.28E-03 | 5.45E-03 | 5.68E-03 |
| Nile Mile Point | 1.42E-02 | 9.35E-03 | 1.39E-02 | 2.57E-02 | 1.67E-02 | 2.11E-02 | | | | | | 7.96E-04 | 1.17E-03 | 2.28E-04 | 1.45E-04 | | |
| Shika | | | | 1.91E-03 | 5.81E-03 | 1.35E-02 | 1.66E-02 | 1.52E-02 | 3.16E-04 | 1.62E-02 | 1.44E-02 | 1.37E-02 | 6.20E-03 | 4.87E-02 | 4.30E-02 | 4.06E-02 | 3.08E-02 |
| Shimane | 1.56E-02 | 1.90E-02 | 1.69E-02 | 1.97E-02 | 3.79E-02 | 2.81E-02 | **4.93E-02** | 2.36E-02 | 1.02E-02 | 1.31E-02 | 2.59E-02 | 1.72E-02 | 1.23E-02 | 2.21E-02 | 2.52E-02 | 2.45E-02 | 1.24E-02 |

| | |
|---|---|
| Mean | 1.34E-02 |
| Standard Deviation | 1.08E-02 |
| Maximum | 2.41E-02 |
| Minimum | 2.57E-03 |
| Prediction | 1.31E-02 |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ▒ | RIFE Reports (RIFE, 1995-2006) |

Data marked in red, has been excluded from the mean and standard deviation calculations

# Table F.2 Other liquid discharges for ESBWR predecessors.

| Candidate Reactor | Raw Data – GBq | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 9.20E-01 | 1.26E+00 | 6.70E-01 | | 4.00E-05 | | 3.00E-05 | | | | | | | | | | |
| Hamaoka | 9.10E-03 | 5.20E-03 | 2.40E-03 | 6.00E-04 | | | | | | | | | | | | | 2.70E-05 |
| Kashiwazaki | | | | | | | | | | | | | | | | | |
| Nile Mile Point | 2.42E+00 | 6.22E+00 | 9.62E+00 | 4.33E+00 | 3.96E+00 | | | | | | | 4.86E+00 | 7.59E-01 | 9.27E-02 | 2.11E-02 | | |
| Shika | | | | | | | | | | | | | | | | | |
| Shimane | 4.60E-04 | 7.00E-05 | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | | | | | | | | | | | | | | | | | |
| Standard Deviation | | | | | | | | | | | | | | | | | |
| Maximum | | | | | | | | | | | | | | | | | |
| Minimum | | | | | | | | | | | | | | | | | |
| Prediction | | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Electrical) – GBq/GWeh | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 2.56E-04 | 2.08E-04 | 1.36E-04 | | 5.40E-09 | | 5.65E-09 | | | | | | | | | | |
| Hamaoka | 6.29E-07 | 3.66E-07 | 1.76E-07 | 2.62E-08 | | | | | | | | | | | | | 1.66E-09 |
| Kashiwazaki | | | | | | | | | | | | | | | | | |
| Nile Mile Point | 4.43E-04 | 5.96E-04 | 1.19E-03 | 3.75E-04 | 2.98E-04 | | | | | | | 3.67E-04 | 5.70E-05 | 6.65E-06 | 1.55E-06 | | |
| Shika | | | | | | | | | | | | | | | | | |
| Shimane | 5.19E-08 | 8.09E-09 | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 1.37E-04 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.88E-04 | | | | | | | | | | | | | | | | |
| Maximum | 3.25E-04 | | | | | | | | | | | | | | | | |
| Minimum | -5.04E-05 | | | | | | | | | | | | | | | | |
| Prediction | 2.65E-04 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Thermal) – GBq/GWth | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 8.22E-05 | 6.69E-05 | 4.36E-05 | | 1.73E-09 | | 1.81E-09 | | | | | | | | | | |
| Hamaoka | 2.10E-07 | 1.22E-07 | 5.87E-08 | 8.75E-09 | | | | | | | | | | | | | 5.52E-10 |
| Kashiwazaki | | | | | | | | | | | | | | | | | |
| Nile Mile Point | 1.50E-04 | 2.02E-04 | 4.04E-04 | 1.27E-04 | 1.01E-04 | | | | | | | 1.24E-04 | 1.93E-05 | 2.25E-06 | 5.25E-07 | | |
| Shika | | | | | | | | | | | | | | | | | |
| Shimane | 1.67E-08 | 2.60E-09 | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 4.60E-05 | | | | | | | | | | | | | | | | |
| Standard Deviation | 6.34E-05 | | | | | | | | | | | | | | | | |
| Maximum | 1.09E-04 | | | | | | | | | | | | | | | | |
| Minimum | -1.74E-05 | | | | | | | | | | | | | | | | |
| Prediction | 9.18E-05 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ◼ | RIFE Reports (RIFE, 1995-2006) |

Data marked in red, has been excluded from the mean and standard deviation calculations

# Table F.3 Airborne tritium discharges for ESBWR predecessors.

| Candidate Reactor | Raw Data – GBq | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 7.00E+01 | 1.93E+02 | 1.76E+02 | 4.22E+02 | 1.16E+03 | 5.70E+02 | 4.40E+02 | | | | 4.16E+01 | 3.74E+01 | 4.61E+01 | 7.71E+01 | 3.21E+01 | | |
| Hamaoka | 8.20E+02 | 7.30E+02 | 7.20E+02 | 7.80E+02 | 5.70E+02 | 6.40E+02 | 8.10E+02 | 8.60E+02 | | | | | | | | | |
| Kashiwazaki | 5.10E+02 | 5.60E+02 | 6.60E+02 | 7.90E+02 | 1.10E+03 | 1.40E+03 | 1.70E+03 | 2.00E+03 | | | | | | | | | |
| Nile Mile Point | 2.06E+03 | 1.14E+03 | 2.06E+03 | 3.57E+03 | 4.32E+03 | | | | | | | 1.29E+02 | 6.18E+01 | 2.51E+02 | 1.17E+02 | | |
| Shika | | | | 1.30E+01 | 6.60E+01 | 9.00E+01 | 7.90E+01 | 1.00E+02 | | | | | | | | | |
| Shimane | 3.10E+02 | 4.10E+02 | 7.50E+02 | 8.80E+02 | 9.90E+02 | 8.20E+02 | 8.70E+02 | 7.70E+02 | | | | | | | | | |
| | 7.00E+01 | 1.93E+02 | 1.76E+02 | 4.22E+02 | 1.16E+03 | 5.70E+02 | 4.40E+02 | | | | | | | | | | |
| Mean | 7.55E+02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 8.53E+02 | | | | | | | | | | | | | | | | |
| Maximum | 1.61E+03 | | | | | | | | | | | | | | | | |
| Minimum | -9.78E+01 | | | | | | | | | | | | | | | | |
| Prediction | 1.40E+04 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Electrical) – GBq/GWeh | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 1.95E-02 | 3.19E-02 | 3.57E-02 | 7.18E-02 | 1.57E-01 | 9.33E-02 | 8.28E-02 | | | | 6.04E-03 | 4.75E-03 | 6.02E-03 | 8.86E-03 | 4.01E-03 | | |
| Hamaoka | 5.67E-02 | 5.13E-02 | 5.28E-02 | 3.41E-02 | 2.88E-02 | 2.31E-02 | 3.24E-02 | 3.41E-02 | | | | | | | | | |
| Kashiwazaki | 2.64E-02 | 2.46E-02 | 2.87E-02 | 2.65E-02 | 3.16E-02 | 3.51E-02 | 3.76E-02 | 3.45E-02 | | | | | | | | | |
| Nile Mile Point | 3.77E-01 | 1.09E-01 | 2.55E-01 | 3.09E-01 | 3.25E-01 | | | | | | | 9.75E-03 | 4.64E-03 | 1.80E-02 | 8.60E-03 | | |
| Shika | | | | 4.59E-03 | 1.99E-02 | 2.57E-02 | 2.29E-02 | 2.26E-02 | | | | | | | | | |
| Shimane | 3.50E-02 | 4.74E-02 | 9.16E-02 | 9.46E-02 | 1.17E-01 | 9.82E-02 | 1.11E-01 | 7.84E-02 | | | | | | | | | |
| Mean | 6.53E-02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 8.36E-02 | | | | | | | | | | | | | | | | |
| Maximum | 1.49E-01 | | | | | | | | | | | | | | | | |
| Minimum | -1.82E-02 | | | | | | | | | | | | | | | | |
| Prediction | 2.05E-01 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Thermal) – GBq/GWth | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 6.25E-03 | 1.03E-02 | 1.15E-02 | 2.31E-02 | 5.03E-02 | 3.00E-02 | 2.66E-02 | | | | 1.94E-03 | 1.53E-03 | 1.93E-03 | 2.85E-03 | 1.29E-03 | | |
| Hamaoka | 1.89E-02 | 1.71E-02 | 1.76E-02 | 1.14E-02 | 9.61E-03 | 7.71E-03 | 1.08E-02 | 1.14E-02 | | | | | | | | | |
| Kashiwazaki | 8.66E-03 | 8.06E-03 | 9.38E-03 | 8.68E-03 | 1.04E-02 | 1.15E-02 | 1.23E-02 | 1.13E-02 | | | | | | | | | |
| Nile Mile Point | 1.28E-01 | 3.70E-02 | 8.64E-02 | 1.05E-01 | 1.10E-01 | | | | | | | 3.30E-03 | 1.57E-03 | 6.11E-03 | 2.91E-03 | | |
| Shika | | | | 1.55E-03 | 6.73E-03 | 8.69E-03 | 7.72E-03 | 7.62E-03 | | | | | | | | | |
| Shimane | 1.12E-02 | 1.52E-02 | 2.95E-02 | 3.04E-02 | 3.75E-02 | 3.16E-02 | 3.58E-02 | 2.52E-02 | | | | | | | | | |
| Mean | 2.16E-02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 2.82E-02 | | | | | | | | | | | | | | | | |
| Maximum | 4.98E-02 | | | | | | | | | | | | | | | | |
| Minimum | -6.59E-03 | | | | | | | | | | | | | | | | |
| Prediction | 7.10E-02 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ▨ | RIFE Reports (RIFE, 1995-2006) |

## Table F.4 Airborne noble gas discharges for ESBWR predecessors.

| Candidate Reactor | Raw Data – GBq | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 3.56E+02 | 2.62E+01 | 2.73E+02 | 3.09E+02 | 4.30E+01 | 5.62E+00 | 4.80E+00 | | | | **5.44E+03** | | 1.31E+00 | 5.84E+00 | 2.65E+01 | | |
| Hamaoka | | | | | 1.90E+02 | | | | | | | | | | | | |
| Kashiwazaki | | | | | | | | | | | | | | | | | |
| Nile Mile Point | 6.03E+03 | 5.57E+03 | 1.38E+04 | 2.00E+04 | 8.58E+03 | | | | | | | 2.91E+01 | 1.68E+01 | 2.51E+02 | 9.42E+01 | | |
| Shika | | | | | | | | | | | | | | | | | |
| Shimane | | | | | | | | | | | | | | | | | |
| Mean | 3.67E+03 | | | | | | | | | | | | | | | | |
| Standard Deviation | 6.04E+03 | | | | | | | | | | | | | | | | |
| Maximum | 9.71E+03 | | | | | | | | | | | | | | | | |
| Minimum | -2.37E+03 | | | | | | | | | | | | | | | | |
| Prediction | 3.06E+05 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Electrical) – GBq/GWeh | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 9.90E-02 | 4.33E-03 | 5.53E-02 | 5.26E-02 | 5.80E-03 | 9.20E-04 | 9.03E-04 | | | | **7.90E-01** | | 1.71E-04 | 6.71E-04 | 3.31E-03 | | |
| Hamaoka | | | | | 9.61E-03 | | | | | | | | | | | | |
| Kashiwazaki | | | | | | | | | | | | | | | | | |
| Nile Mile Point | 1.10E+00 | 5.34E-01 | 1.71E+00 | 1.73E+00 | 6.46E-01 | | | | | | | 2.20E-03 | 1.26E-03 | 1.80E-02 | 6.91E-03 | | |
| Shika | | | | | | | | | | | | | | | | | |
| Shimane | | | | | | | | | | | | | | | | | |
| Mean | 3.92E-01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 6.19E-01 | | | | | | | | | | | | | | | | |
| Maximum | 1.01E+00 | | | | | | | | | | | | | | | | |
| Minimum | -2.27E-01 | | | | | | | | | | | | | | | | |
| Prediction | 1.12E+01 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Thermal) – GBq/GWth | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 3.18E-02 | 1.39E-03 | 1.78E-02 | 1.69E-02 | 1.86E-03 | 2.96E-04 | 2.90E-04 | | | | **2.54E-01** | | 5.50E-05 | 2.16E-04 | 1.06E-03 | | |
| Hamaoka | | | | | 3.20E-03 | | | | | | | | | | | | |
| Kashiwazaki | | | | | | | | | | | | | | | | | |
| Nile Mile Point | 3.74E-01 | 1.81E-01 | 5.79E-01 | 5.87E-01 | 2.19E-01 | | | | | | | 7.44E-04 | 4.28E-04 | 6.11E-03 | 2.34E-03 | | |
| Shika | | | | | | | | | | | | | | | | | |
| Shimane | | | | | | | | | | | | | | | | | |
| Mean | 1.33E-01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 2.10E-01 | | | | | | | | | | | | | | | | |
| Maximum | 3.42E-01 | | | | | | | | | | | | | | | | |
| Minimum | -7.72E-02 | | | | | | | | | | | | | | | | |
| Prediction | 3.88E+00 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ▨ | RIFE Reports (RIFE, 1995-2006) |

Data marked in red, has been excluded from the mean and standard deviation calculations

# Table F.5 Airborne iodine-131 discharges for ESBWR predecessors.

| Candidate Reactor | Raw Data – GBq | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 5.70E-03 | 1.10E-03 | 2.00E-03 | 4.70E-03 | 2.20E-03 | 3.60E-03 | 1.60E-02 | | | | 1.73E-04 | 1.12E-04 | 1.79E-04 | 1.94E-04 | 6.82E-05 | | |
| Hamaoka | 3.70E-02 | | | | | | | | | | | | | | | 2.00E-06 | |
| Kashiwazaki | | | | | | | | | | | | | | | | | |
| Nile Mile Point | 5.30E-02 | 1.90E-01 | 9.00E-02 | 1.70E-01 | 1.50E-02 | | | | | | | 3.28E-03 | 1.98E-03 | 7.23E-04 | 8.56E-04 | | |
| Shika | | | | | | | | | | | | | | | | | |
| Shimane | | | | | | | | | | | | | | | | | |
| Mean | 2.60E-02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 5.32E-02 | | | | | | | | | | | | | | | | |
| Maximum | 7.92E-02 | | | | | | | | | | | | | | | | |
| Minimum | -2.72E-02 | | | | | | | | | | | | | | | | |
| Prediction | 1.51E+01 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Electrical) – GBq/GWeh | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 1.58E-06 | 1.82E-07 | 4.05E-07 | 7.99E-07 | 2.969E-07 | 5.893E-07 | 3.012E-06 | | | | 2.511E-08 | 1.42182E-08 | 2.338E-08 | 2.23E-08 | 8.5246E-09 | | |
| Hamaoka | 2.56E-06 | | | | | | | | | | | | | | | 7.337E-11 | |
| Kashiwazaki | | | | | | | | | | | | | | | | | |
| Nile Mile Point | 9.71E-06 | 1.82E-05 | 1.11E-05 | 1.47E-05 | 1.13E-06 | | | | | | | 2.47816E-07 | 1.488E-07 | 5.188E-08 | 6.2773E-08 | | |
| Shika | | | | | | | | | | | | | | | | | |
| Shimane | | | | | | | | | | | | | | | | | |
| Mean | 2.82E-06 | | | | | | | | | | | | | | | | |
| Standard Deviation | 5.24E-06 | | | | | | | | | | | | | | | | |
| Maximum | 8.06E-06 | | | | | | | | | | | | | | | | |
| Minimum | -2.42E-06 | | | | | | | | | | | | | | | | |
| Prediction | 1.10E-03 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Thermal) – GBq/GWth | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 5.09289E-07 | 5.84E-08 | 1.3E-07 | 2.57E-07 | 9.54E-08 | 1.894E-07 | 9.678E-07 | | | | 8.07E-09 | 4.56907E-09 | 7.512E-09 | 7.165E-09 | 2.7394E-09 | | |
| Hamaoka | 8.52693E-07 | | | | | | | | | | | | | | | 2.447E-11 | |
| Kashiwazaki | | | | | | | | | | | | | | | | | |
| Nile Mile Point | 3.2912E-06 | 6.17E-06 | 3.78E-06 | 4.99E-06 | 3.829E-07 | | | | | | | 8.39785E-08 | 5.041E-08 | 1.758E-08 | 2.1272E-08 | | |
| Shika | | | | | | | | | | | | | | | | | |
| Shimane | | | | | | | | | | | | | | | | | |
| Mean | 9.51E-07 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.78E-06 | | | | | | | | | | | | | | | | |
| Maximum | 2.73E-06 | | | | | | | | | | | | | | | | |
| Minimum | -8.26E-07 | | | | | | | | | | | | | | | | |
| Prediction | 3.83E-04 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ▒ | RIFE Reports (RIFE, 1995-2006) |

# Table F.6 Airborne particulate discharges for ESBWR predecessors.

| **Candidate Reactor** | **Raw Data – GBq** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 3.20E-01 | 3.40E-01 | 9.10E-02 | 6.80E-01 | 1.70E+00 | 1.60E-01 | 3.60E-02 | | | | 7.45E+00 | 7.03E-03 | 1.66E-03 | 3.38E-02 | **4.68E+01** | | |
| Hamaoka | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | |
| Kashiwazaki | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | |
| Nile Mile Point | 2.30E-01 | 5.90E-01 | 3.20E-01 | 3.70E-01 | 1.30E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | | | 0.00E+00 | 1.95E-02 | 6.97E-03 | 7.13E-03 | 8.38E-03 | | |
| Shika | | | | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | | | | | | | | | |
| Shimane | 2.00E-04 | 4.00E-04 | 0.00E+00 | 1.00E-03 | 3.00E-04 | 0.00E+00 | 0.00E+00 | 4.00E-04 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 2.36E-01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.05E+00 | | | | | | | | | | | | | | | | |
| Maximum | 1.28E+00 | | | | | | | | | | | | | | | | |
| Minimum | -8.09E-01 | | | | | | | | | | | | | | | | |
| Prediction | 9.80E+00 | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Electrical) – GBq/GWeh** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 8.90E-05 | 5.62E-05 | 1.84E-05 | 1.16E-04 | 2.29E-04 | 2.62E-05 | 6.78E-06 | | | | 1.08E-03 | 8.92E-07 | 2.17E-07 | 3.88E-06 | **5.85E-03** | | |
| Hamaoka | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | |
| Kashiwazaki | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | |
| Nile Mile Point | 4.21E-05 | 5.65E-05 | 3.96E-05 | 3.21E-05 | 9.79E-06 | 0.00E+00 | 0.00E+00 | 0.00E+00 | | | 0.00E+00 | 1.48E-06 | 5.23E-07 | 5.12E-07 | 6.14E-07 | | |
| Shika | | | | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | | | | | | | | | |
| Shimane | 2.26E-08 | 4.62E-08 | 0.00E+00 | 1.07E-07 | 3.53E-08 | 0.00E+00 | 0.00E+00 | 4.07E-08 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 3.42E-05 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.51E-04 | | | | | | | | | | | | | | | | |
| Maximum | 1.86E-04 | | | | | | | | | | | | | | | | |
| Minimum | -1.17E-04 | | | | | | | | | | | | | | | | |
| Prediction | 3.59E-04 | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Thermal) – GBq/GWth** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Clinton-1 | 2.86E-05 | 1.81E-05 | 5.93E-06 | 3.72E-05 | 7.37E-05 | 8.42E-06 | 2.18E-06 | | | | 3.48E-04 | 2.87E-07 | 6.97E-08 | 1.25E-06 | **1.88E-03** | | |
| Hamaoka | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | |
| Kashiwazaki | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | |
| Nile Mile Point | 1.43E-05 | 1.92E-05 | 1.34E-05 | 1.09E-05 | 3.32E-06 | 0.00E+00 | 0.00E+00 | 0.00E+00 | | | 0.00E+00 | 5.00E-07 | 1.77E-07 | 1.73E-07 | 2.08E-07 | | |
| Shika | | | | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | | | | | | | | | |
| Shimane | 7.26E-09 | 1.49E-08 | 0.00E+00 | 3.46E-08 | 1.14E-08 | 0.00E+00 | 0.00E+00 | 1.31E-08 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 1.10E-05 | | | | | | | | | | | | | | | | |
| Standard Deviation | 4.87E-05 | | | | | | | | | | | | | | | | |
| Maximum | 5.97E-05 | | | | | | | | | | | | | | | | |
| Minimum | -3.76E-05 | | | | | | | | | | | | | | | | |
| Prediction | 1.24E-04 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ▨ | RIFE Reports (RIFE, 1995-2006) |

Data marked in red, has been excluded from the mean and standard deviation calculations

## Table F.7 Airborne carbon-14 discharges for ESBWR predecessors.

| **Candidate Reactor** | **Raw Data – GBq** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Mean | | | | | | | | | | | | | | | | | |
| Standard Deviation | | | | | | | | | | | | | | | | | |
| Maximum | | | | | | | | | | | | | | | | | |
| Minimum | | | | | | | | | | | | | | | | | |
| Prediction | | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Electrical) – GBq/GWeh** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Mean | | | | | | | | | | | | | | | | | |
| Standard Deviation | | | | | | | | | | | | | | | | | |
| Maximum | | | | | | | | | | | | | | | | | |
| Minimum | | | | | | | | | | | | | | | | | |
| Prediction | | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Thermal) – GBq/GWth** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Mean | | | | | | | | | | | | | | | | | |
| Standard Deviation | | | | | | | | | | | | | | | | | |
| Maximum | | | | | | | | | | | | | | | | | |

# Appendix G: Discharge data for ACR-1000 predecessors

## Table G.1 Liquid tritium discharges for ACR-1000 predecessors.

| **Candidate Reactor** | **Raw Data – GBq** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 1.40E+06 | 1.90E+06 | 1.20E+06 | 3.10E+05 | 7.80E+04 | | | | | 6.00E+04 | | | |
| Bruce B | | | | | 5.60E+05 | 3.80E+05 | 2.30E+05 | 6.80E+05 | 3.80E+05 | 2.20E+05 | 2.70E+05 | 1.50E+05 | 3.50E+05 | 8.00E+05 | | | |
| Darlington | | | | | 1.30E+05 | 1.40E+05 | 1.20E+05 | 1.10E+05 | 7.50E+04 | 8.90E+04 | 1.10E+05 | 9.40E+04 | 6.90E+04 | 1.00E+05 | | | |
| Gentilly-2 | | | | | 1.30E+05 | 2.00E+05 | 1.20E+05 | 1.40E+05 | 2.50E+05 | 3.60E+05 | 3.40E+05 | 4.50E+05 | 5.00E+05 | 3.50E+05 | | | |
| Pickering A | | | | | 5.60E+05 | 4.40E+05 | 4.30E+05 | 3.50E+05 | | | | | | 6.60E+04 | | | |
| Pickering B | | | | | 1.20E+05 | 1.10E+05 | 1.60E+04 | 5.00E+04 | 7.10E+04 | 1.30E+05 | 1.10E+05 | 2.00E+05 | 2.10E+05 | 1.90E+05 | | | |
| Point Lepreau | | | | | 2.60E+05 | 1.70E+05 | 4.80E+05 | 5.00E+05 | 1.40E+05 | 5.30E+04 | 9.60E+04 | 1.50E+05 | 1.40E+05 | 8.10E+04 | | | |
| Wolsong | 5.18E+04 | 9.32E+04 | 4.20E+04 | 4.63E+04 | 1.80E+05 | 1.70E+05 | 5.00E+04 | 9.47E+04 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 2.71E+05 | | | | | | | | | | | | | | | | |
| Standard Deviation | 3.19E+05 | | | | | | | | | | | | | | | | |
| Maximum | 5.90E+05 | | | | | | | | | | | | | | | | |
| Minimum | -4.78E+04 | | | | | | | | | | | | | | | | |
| Prediction | 4.80E+05 | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Electrical) – GBq/GWeh** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 9.91E+01 | 1.30E+02 | 9.27E+01 | 3.64E+01 | 4.71E+01 | | | | | 6.42E+01 | | | |
| Bruce B | | | | | 2.33E+01 | 1.64E+01 | 9.19E+00 | 2.87E+01 | 1.96E+01 | 9.75E+00 | 1.15E+01 | 6.20E+00 | 1.67E+01 | 3.37E+01 | | | |
| Darlington | | | | | 4.88E+00 | 5.07E+00 | 4.62E+00 | 5.93E+00 | 2.84E+00 | 3.49E+00 | 4.13E+00 | 3.58E+00 | 2.50E+00 | 4.02E+00 | | | |
| Gentilly-2 | | | | | 2.40E+01 | 4.43E+01 | 2.29E+01 | 3.32E+01 | 6.54E+01 | 9.49E+01 | 6.96E+01 | 9.55E+01 | 1.10E+02 | 9.81E+01 | | | |
| Pickering A | | | | | 4.33E+01 | 5.85E+01 | 6.58E+01 | 3.50E+01 | | | | | | 7.81E+01 | | | |
| Pickering B | | | | | 7.91E+00 | 7.37E+00 | 1.78E+00 | 4.71E+00 | 5.38E+00 | 9.41E+00 | 1.08E+01 | 1.52E+01 | 1.45E+01 | 1.55E+01 | | | |
| Point Lepreau | | | | | 4.97E+01 | 1.05E+02 | 1.05E+02 | 1.45E+02 | 3.70E+01 | 1.30E+01 | 2.42E+01 | 3.37E+01 | 3.72E+01 | 1.71E+01 | | | |
| Wolsong | 1.09E+01 | 1.84E+01 | 8.67E+00 | 8.25E+00 | 3.93E+01 | 3.66E+01 | 1.11E+01 | 1.05E+01 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 3.52E+01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 3.58E+01 | | | | | | | | | | | | | | | | |
| Maximum | 7.09E+01 | | | | | | | | | | | | | | | | |
| Minimum | -5.73E-01 | | | | | | | | | | | | | | | | |
| Prediction | 1.26E+01 | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Thermal) – GBq/GWth** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 3.03E+01 | 3.98E+01 | 2.83E+01 | 1.11E+01 | 1.44E+01 | | | | | 1.96E+01 | | | |
| Bruce B | | | | | 7.28E+00 | 5.11E+00 | 2.87E+00 | 8.96E+00 | 6.11E+00 | 3.04E+00 | 3.60E+00 | 1.94E+00 | 5.20E+00 | 1.05E+01 | | | |
| Darlington | | | | | 1.55E+00 | 1.61E+00 | 1.47E+00 | 1.88E+00 | 9.00E-01 | 1.11E+00 | 1.31E+00 | 1.14E+00 | 7.92E-01 | 1.27E+00 | | | |
| Gentilly-2 | | | | | 7.04E+00 | 1.30E+01 | 6.70E+00 | 9.71E+00 | 1.91E+01 | 2.78E+01 | 2.04E+01 | 2.80E+01 | 3.23E+01 | 2.87E+01 | | | |
| Pickering A | | | | | 1.28E+01 | 1.73E+01 | 1.94E+01 | 1.03E+01 | | | | | | 2.31E+01 | | | |
| Pickering B | | | | | 2.34E+00 | 2.18E+00 | 5.27E-01 | 1.39E+00 | 1.59E+00 | 2.79E+00 | 3.20E+00 | 4.51E+00 | 4.29E+00 | 4.58E+00 | | | |
| Point Lepreau | | | | | 1.45E+01 | 3.07E+01 | 3.05E+01 | 4.21E+01 | 1.08E+01 | 3.78E+00 | 7.05E+00 | 9.82E+00 | 1.08E+01 | 4.98E+00 | | | |
| Wolsong | 3.24E+00 | 5.49E+00 | 2.59E+00 | 2.46E+00 | 1.17E+01 | 1.09E+01 | 3.31E+00 | 3.14E+00 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 1.05E+01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.06E+01 | | | | | | | | | | | | | | | | |
| Maximum | 2.10E+01 | | | | | | | | | | | | | | | | |
| Minimum | -1.00E-01 | | | | | | | | | | | | | | | | |
| Prediction | 4.31E+00 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ⬜ | RIFE Reports (RIFE, 1995-2006) |

## Table G.2 Other liquid discharges for ACR-1000 predecessors.

| Candidate Reactor | Raw Data – GBq | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 4.40E+01 | 2.90E+01 | 2.00E+01 | 2.10E+01 | 2.80E+01 | | | | | 2.58E+00 | | | |
| Bruce B | | | | | 5.90E+00 | 9.60E+00 | 4.50E+00 | 1.50E+01 | 3.40E+00 | 3.74E+01 | 6.90E+00 | 5.50E+00 | 1.01E+01 | 1.26E+01 | | | |
| Darlington | | | | | 1.60E+01 | 1.20E+01 | 2.00E+01 | 9.80E+00 | 3.80E+00 | 1.46E+01 | 1.58E+01 | 8.60E+00 | 1.02E+01 | 8.50E+00 | | | |
| Gentilly-2 | | | | | 1.06E+01 | 5.17E+01 | 1.29E+01 | 1.47E+01 | 3.06E+01 | 1.66E+01 | 3.29E+01 | 3.52E+01 | 2.73E+01 | 3.09E+01 | | | |
| Pickering A | | | | | 3.70E+01 | 1.70E+01 | 1.30E+01 | 7.30E+00 | | | | | | 3.00E+00 | | | |
| Pickering B | | | | | 6.70E+00 | 6.70E+00 | 0.00E+00 | 5.20E+00 | 6.30E+00 | 2.30E+01 | 2.03E+01 | 1.43E+01 | 2.90E+01 | 1.80E+01 | | | |
| Point Lepreau | | | | | 7.30E+00 | 5.90E+00 | 3.20E+00 | 1.37E+01 | 1.24E+01 | 5.90E+00 | 3.00E+00 | 4.10E+00 | 6.40E+00 | 2.80E+00 | | | |
| Wolsong | 2.00E-01 | 2.00E-01 | 3.00E-01 | 5.50E-01 | 4.30E-01 | 1.70E-01 | 0.00E+00 | 0.00E+00 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 1.30E+01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.17E+01 | | | | | | | | | | | | | | | | |
| Maximum | 2.47E+01 | | | | | | | | | | | | | | | | |
| Minimum | 1.28E+00 | | | | | | | | | | | | | | | | |
| Prediction | 1.40E+01 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Electrical) – GBq/GWeh | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 3.12E-03 | 1.99E-03 | 1.55E-03 | 2.46E-03 | 1.69E-02 | | | | | 2.76E-03 | | | |
| Bruce B | | | | | 2.46E-04 | 4.14E-04 | 1.80E-04 | 6.33E-04 | 1.75E-04 | 1.66E-03 | 2.94E-04 | 2.27E-04 | 4.80E-04 | 5.31E-04 | | | |
| Darlington | | | | | 6.00E-04 | 4.34E-04 | 7.71E-04 | 5.28E-04 | 1.44E-04 | 5.72E-04 | 5.93E-04 | 3.28E-04 | 3.69E-04 | 3.41E-04 | | | |
| Gentilly-2 | | | | | 1.96E-03 | 1.14E-02 | 2.46E-03 | 3.49E-03 | 8.00E-03 | 4.38E-03 | 6.74E-03 | 7.47E-03 | 6.02E-03 | 8.65E-03 | | | |
| Pickering A | | | | | 2.86E-03 | 2.26E-03 | 1.99E-03 | 7.30E-04 | | | | | | 3.55E-03 | | | |
| Pickering B | | | | | 4.42E-04 | 4.49E-04 | 0.00E+00 | 4.90E-04 | 4.77E-04 | 1.67E-03 | 1.99E-03 | 1.09E-03 | 2.00E-03 | 1.47E-03 | | | |
| Point Lepreau | | | | | 1.40E-03 | 3.66E-03 | 6.97E-04 | 3.96E-03 | 3.28E-03 | 1.45E-03 | 7.56E-04 | 9.21E-04 | 1.70E-03 | 5.91E-04 | | | |
| Wolsong | 4.19E-05 | 3.95E-05 | 6.19E-05 | 9.80E-05 | 9.38E-05 | 3.66E-05 | 0.00E+00 | 0.00E+00 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 1.80E-03 | | | | | | | | | | | | | | | | |
| Standard Deviation | 2.32E-03 | | | | | | | | | | | | | | | | |
| Maximum | 4.11E-03 | | | | | | | | | | | | | | | | |
| Minimum | -5.18E-04 | | | | | | | | | | | | | | | | |
| Prediction | 1.47E-03 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Thermal) – GBq/GWth | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 9.52E-04 | 6.08E-04 | 4.72E-04 | 7.54E-04 | 5.17E-03 | | | | | 8.44E-04 | | | |
| Bruce B | | | | | 7.67E-05 | 1.29E-04 | 5.61E-05 | 1.98E-04 | 5.47E-05 | 5.17E-04 | 9.19E-05 | 7.10E-05 | 1.50E-04 | 1.66E-04 | | | |
| Darlington | | | | | 1.90E-04 | 1.38E-04 | 2.44E-04 | 1.67E-04 | 4.56E-05 | 1.81E-04 | 1.88E-04 | 1.04E-04 | 1.17E-04 | 1.08E-04 | | | |
| Gentilly-2 | | | | | 5.74E-04 | 3.35E-03 | 7.20E-04 | 1.02E-03 | 2.34E-03 | 1.28E-03 | 1.97E-03 | 2.19E-03 | 1.76E-03 | 2.53E-03 | | | |
| Pickering A | | | | | 8.45E-04 | 6.68E-04 | 5.88E-04 | 2.16E-04 | | | | | | 1.05E-03 | | | |
| Pickering B | | | | | 1.31E-04 | 1.33E-04 | 0.00E+00 | 1.45E-04 | 1.41E-04 | 4.93E-04 | 5.90E-04 | 3.22E-04 | 5.92E-04 | 4.34E-04 | | | |
| Point Lepreau | | | | | 4.07E-04 | 1.07E-03 | 2.03E-04 | 1.15E-03 | 9.55E-04 | 4.21E-04 | 2.20E-04 | 2.68E-04 | 4.96E-04 | 1.72E-04 | | | |
| Wolsong | 1.25E-05 | 1.18E-05 | 1.85E-05 | 2.92E-05 | 2.80E-05 | 1.09E-05 | 0.00E+00 | 0.00E+00 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 5.32E-04 | | | | | | | | | | | | | | | | |
| Standard Deviation | 6.77E-04 | | | | | | | | | | | | | | | | |
| Maximum | 1.21E-03 | | | | | | | | | | | | | | | | |
| Minimum | -1.45E-04 | | | | | | | | | | | | | | | | |
| Prediction | 5.03E-04 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ▨ | RIFE Reports (RIFE, 1995-2006) |

## Table G.3 Airborne tritium discharges for ACR-1000 predecessors.

| Candidate Reactor | Raw Data – GBq | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 1.00E+06 | 6.10E+05 | 7.00E+05 | 3.50E+05 | 2.30E+05 | | | | | 1.90E+05 | | | |
| Bruce B | | | | | 3.70E+05 | 2.30E+05 | 3.10E+05 | 2.70E+05 | 2.60E+05 | 3.10E+05 | 4.90E+05 | 4.20E+05 | 4.30E+05 | 3.70E+05 | | | |
| Darlington | | | | | 3.30E+05 | 2.70E+05 | 2.00E+05 | 1.90E+05 | 1.90E+05 | 2.20E+05 | 2.30E+05 | 2.40E+05 | 1.90E+05 | 1.70E+05 | | | |
| Gentilly-2 | | | | | 2.60E+05 | 3.10E+05 | 2.20E+05 | 1.60E+05 | 1.40E+05 | 1.30E+05 | 2.50E+05 | 1.90E+05 | 1.80E+05 | 1.50E+05 | | | |
| Pickering A | | | | | 4.80E+05 | 5.90E+05 | 3.70E+05 | 4.40E+05 | | | | | | 1.70E+05 | | | |
| Pickering B | | | | | 2.30E+05 | 1.90E+05 | 1.90E+05 | 1.70E+05 | 2.20E+05 | 2.70E+05 | 2.70E+05 | 2.70E+05 | 2.80E+05 | 3.10E+05 | | | |
| Point Lepreau | | | | | 5.20E+05 | 3.10E+05 | 2.40E+05 | 2.00E+05 | 1.30E+05 | 1.10E+05 | 1.30E+05 | 1.40E+05 | 1.30E+05 | 1.00E+05 | | | |
| Wolsong | 2.31E+05 | 2.57E+05 | 3.89E+05 | 3.68E+05 | 4.80E+05 | 4.40E+05 | 3.10E+05 | 6.25E+05 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 2.88E+05 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.50E+05 | | | | | | | | | | | | | | | | |
| Maximum | 4.37E+05 | | | | | | | | | | | | | | | | |
| Minimum | 1.38E+05 | | | | | | | | | | | | | | | | |
| Prediction | 2.00E+05 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Electrical) – GBq/GWeh | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 7.08E+01 | 4.18E+01 | 5.41E+01 | 4.11E+01 | 1.39E+02 | | | | | 2.03E+02 | | | |
| Bruce B | | | | | 1.54E+01 | 9.92E+00 | 1.24E+01 | 1.14E+01 | 1.34E+01 | 1.37E+01 | 2.09E+01 | 1.74E+01 | 2.05E+01 | 1.56E+01 | | | |
| Darlington | | | | | 1.24E+01 | 9.78E+00 | 7.71E+00 | 1.02E+01 | 7.19E+00 | 8.63E+00 | 8.63E+00 | 9.15E+00 | 6.88E+00 | 6.83E+00 | | | |
| Gentilly-2 | | | | | 4.81E+01 | 6.86E+01 | 4.20E+01 | 3.79E+01 | 3.66E+01 | 3.43E+01 | 5.12E+01 | 4.03E+01 | 3.97E+01 | 4.21E+01 | | | |
| Pickering A | | | | | 3.71E+01 | 7.85E+01 | 5.66E+01 | 4.40E+01 | | | | | | 2.01E+02 | | | |
| Pickering B | | | | | 1.52E+01 | 1.27E+01 | 2.11E+01 | 1.60E+01 | 1.67E+01 | 1.96E+01 | 2.65E+01 | 2.06E+01 | 1.93E+01 | 2.53E+01 | | | |
| Point Lepreau | | | | | 9.94E+01 | 1.92E+02 | 5.23E+01 | 5.79E+01 | 3.44E+01 | 2.69E+01 | 3.28E+01 | 3.15E+01 | 3.46E+01 | 2.11E+01 | | | |
| Wolsong | 4.84E+01 | 5.08E+01 | 8.03E+01 | 6.56E+01 | 1.05E+02 | 9.47E+01 | 6.88E+01 | 6.96E+01 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 4.05E+01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 4.09E+01 | | | | | | | | | | | | | | | | |
| Maximum | 8.14E+01 | | | | | | | | | | | | | | | | |
| Minimum | -4.65E-01 | | | | | | | | | | | | | | | | |
| Prediction | 5.26E+00 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Thermal) – GBq/GWth | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 2.16E+01 | 1.28E+01 | 1.65E+01 | 1.26E+01 | 4.25E+01 | | | | | 6.22E+01 | | | |
| Bruce B | | | | | 4.81E+00 | 3.09E+00 | 3.87E+00 | 3.56E+00 | 4.18E+00 | 4.29E+00 | 6.53E+00 | 5.42E+00 | 6.38E+00 | 4.86E+00 | | | |
| Darlington | | | | | 3.93E+00 | 3.10E+00 | 2.44E+00 | 3.25E+00 | 2.28E+00 | 2.74E+00 | 2.74E+00 | 2.90E+00 | 2.18E+00 | 2.16E+00 | | | |
| Gentilly-2 | | | | | 1.41E+01 | 2.01E+01 | 1.23E+01 | 1.11E+01 | 1.07E+01 | 1.00E+01 | 1.50E+01 | 1.18E+01 | 1.16E+01 | 1.23E+01 | | | |
| Pickering A | | | | | 1.10E+01 | 2.32E+01 | 1.67E+01 | 1.30E+01 | | | | | | 5.94E+01 | | | |
| Pickering B | | | | | 4.49E+00 | 3.76E+00 | 6.26E+00 | 4.74E+00 | 4.93E+00 | 5.79E+00 | 7.85E+00 | 6.09E+00 | 5.72E+00 | 7.47E+00 | | | |
| Point Lepreau | | | | | 2.90E+01 | 5.60E+01 | 1.52E+01 | 1.69E+01 | 1.00E+01 | 7.85E+00 | 9.55E+00 | 9.16E+00 | 1.01E+01 | 6.15E+00 | | | |
| Wolsong | 1.44E+01 | 1.51E+01 | 2.39E+01 | 1.96E+01 | 3.12E+01 | 2.82E+01 | 2.05E+01 | 2.07E+01 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 1.21E+01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.22E+01 | | | | | | | | | | | | | | | | |
| Maximum | 2.43E+01 | | | | | | | | | | | | | | | | |
| Minimum | -1.30E-01 | | | | | | | | | | | | | | | | |
| Prediction | 1.79E+00 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ⬜ | RIFE Reports (RIFE, 1995-2006) |

## Table G.4 Airborne noble gas discharges for ACR-1000 predecessors.

| Candidate Reactor | Raw Data – GBq | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 2.50E+05 | 1.00E+05 | 8.80E+04 | 5.40E+04 | 3.10E+04 | | | | | 1.40E+04 | | | |
| Bruce B | | | | | 7.00E+04 | 6.70E+04 | 7.00E+04 | 7.40E+04 | 6.20E+04 | 7.90E+04 | 7.20E+04 | 6.10E+04 | 5.60E+04 | 5.10E+04 | | | |
| Darlington | | | | | 1.40E+05 | 1.10E+05 | 3.80E+05 | 3.00E+05 | 3.50E+05 | 3.40E+05 | 1.50E+05 | 1.80E+04 | 1.50E+04 | 1.30E+04 | | | |
| Gentilly-2 | | | | | 5.90E+04 | 7.30E+04 | 5.40E+04 | 2.10E+04 | 3.40E+03 | 3.80E+03 | 2.60E+03 | 1.90E+03 | 6.90E+02 | 7.10E+02 | | | |
| Pickering A | | | | | 3.40E+05 | 3.10E+05 | 3.10E+05 | 2.90E+05 | | | | | | 2.80E+05 | | | |
| Pickering B | | | | | 2.20E+05 | 2.20E+05 | 2.00E+05 | 2.10E+05 | 2.20E+05 | 2.10E+05 | 2.10E+05 | 2.10E+05 | 2.00E+05 | 2.00E+05 | | | |
| Point Lepreau | | | | | 5.10E+03 | 2.20E+03 | 5.60E+03 | 5.90E+03 | 3.40E+03 | 3.80E+03 | 5.00E+03 | 5.90E+03 | 3.20E+03 | 4.60E+03 | | | |
| Wolsong | 1.12E+05 | 1.14E+05 | 6.59E+04 | 2.19E+05 | 1.20E+05 | 7.50E+05 | 3.20E+06 | 6.03E+04 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 1.13E+05 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.11E+05 | | | | | | | | | | | | | | | | |
| Maximum | 2.25E+05 | | | | | | | | | | | | | | | | |
| Minimum | 2.38E+03 | | | | | | | | | | | | | | | | |
| Prediction | 6.40E+04 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Electrical) – GBq/GWeh | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 1.77E+01 | 6.86E+00 | 6.80E+00 | 6.34E+00 | 1.87E+01 | | | | | 1.50E+01 | | | |
| Bruce B | | | | | 2.91E+00 | 2.89E+00 | 2.80E+00 | 3.12E+00 | 3.19E+00 | 3.50E+00 | 3.07E+00 | 2.52E+00 | 2.66E+00 | 2.15E+00 | | | |
| Darlington | | | | | 5.25E+00 | 3.98E+00 | 1.46E+01 | 1.62E+01 | 1.32E+01 | 1.33E+01 | 5.63E+00 | 6.86E-01 | 5.43E-01 | 5.22E-01 | | | |
| Gentilly-2 | | | | | 1.09E+01 | 1.62E+01 | 1.03E+01 | 4.98E+00 | 8.89E-01 | 1.00E+00 | 5.32E-01 | 4.03E-01 | 1.52E-01 | 1.99E-01 | | | |
| Pickering A | | | | | 2.63E+01 | 4.12E+01 | 4.74E+01 | 2.90E+01 | | | | | | 3.31E+02 | | | |
| Pickering B | | | | | 1.45E+01 | 1.47E+01 | 2.23E+01 | 1.98E+01 | 1.67E+01 | 1.52E+01 | 2.06E+01 | 1.60E+01 | 1.38E+01 | 1.63E+01 | | | |
| Point Lepreau | | | | | 9.75E-01 | 1.37E+00 | 1.22E+00 | 1.71E+00 | 8.99E-01 | 9.31E-01 | 1.26E+00 | 1.33E+00 | 8.51E-01 | 9.71E-01 | | | |
| Wolsong | 2.35E+01 | 2.25E+01 | 1.36E+01 | 3.90E+01 | 2.62E+01 | 1.61E+02 | 7.10E+02 | 6.71E+00 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 1.50E+01 | | | | | | | | | | | | | | | | |
| Standard Deviation | 4.07E+01 | | | | | | | | | | | | | | | | |
| Maximum | 5.57E+01 | | | | | | | | | | | | | | | | |
| Minimum | -2.56E+01 | | | | | | | | | | | | | | | | |
| Prediction | 1.68E+00 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Thermal) – GBq/GWth | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 5.41E+00 | 2.10E+00 | 2.08E+00 | 1.94E+00 | 5.73E+00 | | | | | 4.58E+00 | | | |
| Bruce B | | | | | 9.10E-01 | 9.02E-01 | 8.73E-01 | 9.75E-01 | 9.97E-01 | 1.09E+00 | 9.59E-01 | 7.87E-01 | 8.32E-01 | 6.70E-01 | | | |
| Darlington | | | | | 1.67E+00 | 1.26E+00 | 4.64E+00 | 5.13E+00 | 4.20E+00 | 4.23E+00 | 1.78E+00 | 2.18E-01 | 1.72E-01 | 1.65E-01 | | | |
| Gentilly-2 | | | | | 3.19E+00 | 4.73E+00 | 3.01E+00 | 1.46E+00 | 2.60E-01 | 2.93E-01 | 1.56E-01 | 1.18E-01 | 4.46E-02 | 5.83E-02 | | | |
| Pickering A | | | | | 7.77E+00 | 1.22E+01 | 1.40E+01 | 8.56E+00 | | | | | | 9.79E+01 | | | |
| Pickering B | | | | | 4.29E+00 | 4.36E+00 | 6.59E+00 | 5.86E+00 | 4.93E+00 | 4.50E+00 | 6.10E+00 | 4.74E+00 | 4.08E+00 | 4.82E+00 | | | |
| Point Lepreau | | | | | 2.84E-01 | 3.98E-01 | 3.56E-01 | 4.97E-01 | 2.62E-01 | 2.71E-01 | 3.67E-01 | 3.86E-01 | 2.48E-01 | 2.83E-01 | | | |
| Wolsong | 7.00E+00 | 6.71E+00 | 4.06E+00 | 1.16E+01 | 7.81E+00 | 4.81E+01 | 2.12E+02 | 2.00E+00 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 4.49E+00 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.20E+01 | | | | | | | | | | | | | | | | |
| Maximum | 1.65E+01 | | | | | | | | | | | | | | | | |
| Minimum | -7.52E+00 | | | | | | | | | | | | | | | | |
| Prediction | 5.74E-01 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ▨ | RIFE Reports (RIFE, 1995-2006) |

## Table G.5 Airborne iodine-131 discharges for ACR-1000 predecessors.

| Candidate Reactor | Raw Data – GBq | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 3.00E-02 | 2.70E-02 | 1.90E-02 | 1.40E-02 | 9.90E-03 | | | | | 2.10E-03 | | | |
| Bruce B | | | | | 5.90E-02 | 1.20E-01 | 4.40E-02 | 3.50E-02 | 4.00E-02 | 3.50E-02 | 5.50E-02 | 2.80E-02 | 4.90E-02 | 3.20E-02 | | | |
| Darlington | | | | | 3.60E-02 | 3.40E-02 | 2.20E-02 | 2.00E-02 | 2.10E-02 | 3.20E-02 | 7.50E-02 | 1.30E-01 | 1.50E-01 | 1.40E-01 | | | |
| Gentilly-2 | | | | | | | | | | | 6.40E-05 | | 1.40E-04 | | | | |
| Pickering A | | | | | 1.00E-01 | 7.40E-02 | 7.30E-02 | 7.40E-02 | | | | | | 6.40E-02 | | | |
| Pickering B | | | | | 8.50E-02 | 1.00E-01 | 9.80E-02 | 9.90E-02 | 9.70E-02 | 9.60E-02 | 9.80E-02 | 1.00E-01 | 9.80E-02 | 9.70E-02 | | | |
| Point Lepreau | | | | | 5.10E-03 | | 1.50E-03 | 2.10E-02 | | | | | | | | | |
| Wolsong | 0.00E+00 | 1.20E-03 | 3.70E-04 | 0.00E+00 | 0.00E+00 | 5.20E-02 | 1.40E-01 | 0.00E+00 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 5.25E-02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 4.37E-02 | | | | | | | | | | | | | | | | |
| Maximum | 9.62E-02 | | | | | | | | | | | | | | | | |
| Minimum | 8.78E-03 | | | | | | | | | | | | | | | | |
| Prediction | 8.00E-03 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Electrical) – GBq/GWeh | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 2.12E-06 | 1.85E-06 | 1.47E-06 | 1.64E-06 | 5.98E-06 | | | | | 2.25E-06 | | | |
| Bruce B | | | | | 2.46E-06 | 5.17E-06 | 1.76E-06 | 1.48E-06 | 2.06E-06 | 1.55E-06 | 2.35E-06 | 1.16E-06 | 2.33E-06 | 1.35E-06 | | | |
| Darlington | | | | | 1.35E-06 | 1.23E-06 | 8.48E-07 | 1.08E-06 | 7.95E-07 | 1.26E-06 | 2.81E-06 | 4.96E-06 | 5.43E-06 | 5.62E-06 | | | |
| Gentilly-2 | | | | | | | | | | | 1.31E-08 | | 3.09E-08 | | | | |
| Pickering A | | | | | 7.74E-06 | 9.84E-06 | 1.12E-05 | 7.40E-06 | | | | | | 7.58E-05 | | | |
| Pickering B | | | | | 5.60E-06 | 6.70E-06 | 1.09E-05 | 9.33E-06 | 7.35E-06 | 6.95E-06 | 9.63E-06 | 7.62E-06 | 6.76E-06 | 7.90E-06 | | | |
| Point Lepreau | | | | | 9.75E-07 | | 3.27E-07 | 6.08E-06 | | | | | | | | | |
| Wolsong | 0.00E+00 | 2.37E-07 | 7.64E-08 | 0.00E+00 | 0.00E+00 | 1.12E-05 | 3.11E-05 | 0.00E+00 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 5.61E-06 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.10E-05 | | | | | | | | | | | | | | | | |
| Maximum | 1.66E-05 | | | | | | | | | | | | | | | | |
| Minimum | -5.34E-06 | | | | | | | | | | | | | | | | |
| Prediction | 8.42E-07 | | | | | | | | | | | | | | | | |

| Candidate Reactor | Normalised Data (Thermal) – GBq/GWth | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 6.49E-07 | 5.66E-07 | 4.49E-07 | 5.02E-07 | 1.83E-06 | | | | | 6.87E-07 | | | |
| Bruce B | | | | | 7.67E-07 | 1.61E-06 | 5.49E-07 | 4.61E-07 | 6.43E-07 | 4.84E-07 | 7.33E-07 | 3.61E-07 | 7.28E-07 | 4.21E-07 | | | |
| Darlington | | | | | 4.28E-07 | 3.90E-07 | 2.69E-07 | 3.42E-07 | 2.52E-07 | 3.98E-07 | 8.92E-07 | 1.57E-06 | 1.72E-06 | 1.78E-06 | | | |
| Gentilly-2 | | | | | | | | | | | 3.83E-09 | | 9.04E-09 | | | | |
| Pickering A | | | | | 2.28E-06 | 2.91E-06 | 3.30E-06 | 2.19E-06 | | | | | | 2.24E-05 | | | |
| Pickering B | | | | | 1.66E-06 | 1.98E-06 | 3.23E-06 | 2.76E-06 | 2.17E-06 | 2.06E-06 | 2.85E-06 | 2.25E-06 | 2.00E-06 | 2.34E-06 | | | |
| Point Lepreau | | | | | 2.84E-07 | | 9.52E-08 | 1.77E-06 | | | | | | | | | |
| Wolsong | 0.00E+00 | 7.07E-08 | 2.28E-08 | 0.00E+00 | 0.00E+00 | 3.34E-06 | 9.26E-06 | 0.00E+00 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Mean | 1.68E-06 | | | | | | | | | | | | | | | | |
| Standard Deviation | 3.24E-06 | | | | | | | | | | | | | | | | |
| Maximum | 4.91E-06 | | | | | | | | | | | | | | | | |
| Minimum | -1.56E-06 | | | | | | | | | | | | | | | | |
| Prediction | 2.87E-07 | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ⬜ | RIFE Reports (RIFE, 1995-2006) |

## Table G.6 Airborne particulate discharges for ACR-1000 predecessors.

| **Candidate Reactor** | **Raw Data – GBq** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 1.10E-01 | 1.20E-01 | 7.20E-02 | 7.00E-02 | 5.60E-02 | | | | | 2.90E-03 | | | |
| Bruce B | | | | | 1.00E-01 | 1.20E-01 | 7.50E-02 | 8.80E-02 | 9.60E-02 | 1.10E-01 | 7.90E-02 | 1.40E-01 | 1.10E-01 | 1.10E-01 | | | |
| Darlington | | | | | 1.00E-01 | 8.50E-02 | 5.80E-02 | 6.50E-02 | 6.50E-02 | 8.20E-02 | 8.60E-02 | 5.60E-02 | 8.70E-02 | 6.90E-02 | | | |
| Gentilly-2 | | | | | 7.00E-02 | 4.50E-02 | 3.00E-02 | 1.10E-01 | 6.40E-03 | 7.40E-03 | 9.00E-03 | 8.30E-03 | 5.00E-03 | 5.40E-03 | | | |
| Pickering A | | | | | 7.00E-02 | 7.00E-02 | 5.10E-02 | 3.60E-01 | | | | | | 3.40E-01 | | | |
| Pickering B | | | | | 4.10E-02 | 2.60E-02 | 2.70E-02 | 3.90E-02 | 4.00E-02 | 5.70E-02 | 2.40E-02 | 2.60E-02 | 2.00E-02 | 1.60E-02 | | | |
| Point Lepreau | | | | | 5.20E-04 | | | 5.00E-05 | 1.00E-03 | 3.50E-03 | 1.10E-03 | | | | | | |
| Wolsong | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | | | | | | | | | |
| Mean | 5.81E-02 | | | | | | | | | | | | | | | | |
| Standard Deviation | 6.67E-02 | | | | | | | | | | | | | | | | |
| Maximum | 1.25E-01 | | | | | | | | | | | | | | | | |
| Minimum | -8.55E-03 | | | | | | | | | | | | | | | | |
| Prediction | – | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Electrical) – GBq/GWeh** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 7.79E-06 | 8.23E-06 | 5.56E-06 | 8.21E-06 | 3.38E-05 | | | | | 3.10E-06 | | | |
| Bruce B | | | | | 4.16E-06 | 5.17E-06 | 3.00E-06 | 3.72E-06 | 4.94E-06 | 4.87E-06 | 3.37E-06 | 5.79E-06 | 5.23E-06 | 4.63E-06 | | | |
| Darlington | | | | | 3.75E-06 | 3.08E-06 | 2.24E-06 | 3.50E-06 | 2.46E-06 | 3.22E-06 | 3.23E-06 | 2.14E-06 | 3.15E-06 | 2.77E-06 | | | |
| Gentilly-2 | | | | | 1.29E-05 | 9.96E-06 | 5.72E-06 | 2.61E-05 | 1.67E-06 | 1.95E-06 | 1.84E-06 | 1.76E-06 | 1.10E-06 | 1.51E-06 | | | |
| Pickering A | | | | | 5.42E-06 | 9.31E-06 | 7.81E-06 | 3.60E-05 | | | | | | 4.02E-04 | | | |
| Pickering B | | | | | 2.70E-06 | 1.74E-06 | 3.00E-06 | 3.68E-06 | 3.03E-06 | 4.13E-06 | 2.36E-06 | 1.98E-06 | 1.38E-06 | 1.30E-06 | | | |
| Point Lepreau | | | | | 9.94E-08 | | | 1.45E-08 | 2.64E-07 | 8.57E-07 | 2.77E-07 | | | | | | |
| Wolsong | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | | | | | | | | | |
| Mean | 1.08E-05 | | | | | | | | | | | | | | | | |
| Standard Deviation | 5.02E-05 | | | | | | | | | | | | | | | | |
| Maximum | 6.10E-05 | | | | | | | | | | | | | | | | |
| Minimum | -3.94E-05 | | | | | | | | | | | | | | | | |
| Prediction | - | | | | | | | | | | | | | | | | |

| **Candidate Reactor** | **Normalised Data (Thermal) – GBq/GWth** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Bruce A | | | | | 2.38E-06 | 2.52E-06 | 1.70E-06 | 2.51E-06 | 1.03E-05 | | | | | 9.49E-07 | | | |
| Bruce B | | | | | 1.30E-06 | 1.61E-06 | 9.35E-07 | 1.16E-06 | 1.54E-06 | 1.52E-06 | 1.05E-06 | 1.81E-06 | 1.63E-06 | 1.45E-06 | | | |
| Darlington | | | | | 1.19E-06 | 9.76E-07 | 7.09E-07 | 1.11E-06 | 7.80E-07 | 1.02E-06 | 1.02E-06 | 6.77E-07 | 9.98E-07 | 8.78E-07 | | | |
| Gentilly-2 | | | | | 3.79E-06 | 2.91E-06 | 1.67E-06 | 7.63E-06 | 4.90E-07 | 5.71E-07 | 5.39E-07 | 5.16E-07 | 3.23E-07 | 4.43E-07 | | | |
| Pickering A | | | | | 1.60E-06 | 2.75E-06 | 2.30E-06 | 1.06E-05 | | | | | | 1.19E-04 | | | |
| Pickering B | | | | | 8.00E-07 | 5.15E-07 | 8.89E-07 | 1.09E-06 | 8.97E-07 | 1.22E-06 | 6.98E-07 | 5.86E-07 | 4.08E-07 | 3.86E-07 | | | |
| Point Lepreau | | | | | 2.90E-08 | | | 4.21E-09 | 7.70E-08 | 2.50E-07 | 8.08E-08 | | | | | | |
| Wolsong | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | | | | | | | | | |
| Mean | 3.23E-06 | | | | | | | | | | | | | | | | |
| Standard Deviation | 1.48E-05 | | | | | | | | | | | | | | | | |
| Maximum | 1.80E-05 | | | | | | | | | | | | | | | | |
| Minimum | -1.16E-05 | | | | | | | | | | | | | | | | |
| Prediction | - | | | | | | | | | | | | | | | | |

| Colour Code | Information source |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ▨ | RIFE Reports (RIFE, 1995-2006) |

## Table G.7 Airborne carbon-14 discharges for ACR-1000 predecessors.

**Raw Data – GBq**

| **Candidate Reactor** | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bruce A | | | | | | | | | | | | | | 5.10E+02 | | | |
| Bruce B | | | | | | | | | | | 4.10E+03 | 2.70E+03 | 2.10E+03 | 4.30E+03 | | | |
| Darlington | | | | | | | | | | 3.50E+03 | 2.80E+03 | 2.60E+03 | 2.80E+03 | 3.50E+03 | | | |
| Gentilly-2 | | | | | 2.90E+03 | 1.20E+03 | 1.60E+03 | 5.00E+02 | 2.70E+02 | 2.50E+02 | 2.30E+02 | 4.00E+02 | 3.70E+02 | 3.90E+02 | | | |
| Pickering A | | | | | 1.20E+03 | 4.10E+03 | 2.30E+02 | 1.10E+03 | | | | | | 1.10E+03 | | | |
| Pickering B | | | | | | | | | | | **1.10E+04** | 6.30E+03 | 1.80E+03 | 2.60E+03 | | | |
| Point Lepreau | | | | | 2.00E+02 | 1.40E+02 | 1.20E+02 | 1.50E+02 | 3.20E+02 | 2.80E+02 | 2.30E+02 | 2.20E+02 | 2.90E+02 | 2.10E+02 | | | |
| Wolsong | | | | | | | | | | | | | | 5.10E+02 | | | |

| | |
|---|---|
| Mean | 1.52E+03 |
| Standard Deviation | 1.57E+03 |
| Maximum | 3.08E+03 |
| Minimum | -5.29E+01 |
| Prediction | 2.80E+02 |

**Normalised Data (Electrical) – GBq/GWeh**

| **Candidate Reactor** | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bruce A | | | | | | | | | | | | | | 5.46E-01 | | | |
| Bruce B | | | | | | | | | | | 1.75E-01 | 1.12E-01 | 9.99E-02 | 1.81E-01 | | | |
| Darlington | | | | | | | | | | 1.37E-01 | 1.05E-01 | 9.92E-02 | 1.01E-01 | 1.41E-01 | | | |
| Gentilly-2 | | | | | 5.36E-01 | 2.66E-01 | 3.05E-01 | 1.19E-01 | 7.06E-02 | 6.59E-02 | 4.71E-02 | 8.49E-02 | 8.16E-02 | 1.09E-01 | | | |
| Pickering A | | | | | 9.28E-02 | 5.45E-01 | 3.52E-02 | 1.10E-01 | | | | | | 1.30E+00 | | | |
| Pickering B | | | | | | | | | | | **1.08E+00** | 4.80E-01 | 1.24E-01 | 2.12E-01 | | | |
| Point Lepreau | | | | | 3.82E-02 | 8.69E-02 | 2.62E-02 | 4.34E-02 | 8.46E-02 | 6.86E-02 | 5.80E-02 | 4.94E-02 | 7.71E-02 | 4.43E-02 | | | |

| | |
|---|---|
| Mean | 1.81E-01 |
| Standard Deviation | 2.36E-01 |
| Maximum | 4.17E-01 |
| Minimum | -5.55E-02 |
| Prediction | 2.95E-02 |

**Normalised Data (Thermal) – GBq/GWth**

| **Candidate Reactor** | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bruce A | | | | | | | | | | | | | | 1.67E-01 | | | |
| Bruce B | | | | | | | | | | | 5.46E-02 | 3.48E-02 | 3.12E-02 | 5.65E-02 | | | |
| Darlington | | | | | | | | | | 4.35E-02 | 3.33E-02 | 3.14E-02 | 3.21E-02 | 4.46E-02 | | | |
| Gentilly-2 | | | | | 1.57E-01 | 7.77E-02 | 8.93E-02 | 3.47E-02 | 2.07E-02 | 1.93E-02 | 1.38E-02 | 2.48E-02 | 2.39E-02 | 3.20E-02 | | | |
| Pickering A | | | | | 2.74E-02 | 1.61E-01 | 1.04E-02 | 3.25E-02 | | | | | | 3.84E-01 | | | |
| Pickering B | | | | | | | | | | | **3.20E-01** | 1.42E-01 | 3.68E-02 | 6.27E-02 | | | |
| Point Lepreau | | | | | 1.11E-02 | 2.53E-02 | 7.62E-03 | 1.26E-02 | 2.46E-02 | 2.00E-02 | 1.69E-02 | 1.44E-02 | 2.25E-02 | 1.29E-02 | | | |

| | |
|---|---|
| Mean | 5.39E-02 |
| Standard Deviation | 6.98E-02 |
| Maximum | 1.24E-01 |
| Minimum | -1.59E-02 |
| Prediction | 1.01E-02 |

| **Colour Code** | **Information source** |
|---|---|
| 🟦 | UNSCEAR report (UNSCEAR, 2000) |
| 🟨 | NRC Effluents Database (NRC, 2008) |
| 🟩 | JNES Report (JNES, 2007) |
| 🟧 | CNSC Report (CNSC, 2005) |
| 🟪 | EU Report (EU, 1995-2003) |
| ▒ | RIFE Reports (RIFE, 1995-2006) |

Data marked in red, has been excluded from the mean and standard deviation calculations

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